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Woods Hole Oceanographic Institution

A Large-Volume, Deep-Sea Submersible Pumping System

by

P.L. Sachs, T.R. Hammar, and M.P. Bacon

with an Appendix by Alan P. Fleer

November 1989

Technical Report

Funding was provided by the National Science Foundation under Grant Number NSF OCE-8800620 and the Department of Energy under Grant DE-FG02-88ER60681.

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Approved for Distribution:

Frederick L. Sayles, Chairman
Department of Chemistry

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ABSTRACT

Eight self-contained, in-situ pumps have been used effectively and routinely by our group for the past six years to collect both particulate and dissolved phases from large volumes of sea water. Multiple pumps are rapidly and easily deployed on the same wire, to any ocean depth, in almost any weather. Each is capable of drawing up to 200 liters per hour through four large Nuclepore^{TM} filters, then through three cartridge filters. Pumping is controlled by a Sharp^{TM} pocket computer suitably interfaced with the pump motor and flow meter. Endurance is about 15 hours. Total flow and flow rate are recorded, respectively, by a mechanical flow meter and the computer.

INTRODUCTION

In-situ pumps of the basic design and capabilities discussed here were first used to filter biological material from shallow water (Laird et al., 1967). A similar pump/filter design but with a much greater depth capability and self-contained power supply was used for studies of the nepheloid layer in the Gulf of Maine (Spencer & Sachs, 1970) and subsequently for collecting deep particulates as part of the GEOSECS program (Krishnaswami et al., 1976). These self-contained designs used pressure-equalized batteries to power the pump. Winget (1982) designed a system using batteries in pressure housings, and this eliminated messy hazards caused by oil and acid.

The pumps described here evolved from these prototypes and represent, we think, a successful effort to increase the reliability, ruggedness, and ease of deployment. Among the numerous pumping systems described elsewhere (for example, Winget (1978, 1980), Bishop and Edmond (1976), Bishop et al. (1985), Simpson (1987), Orr et al. (1984)), this system is unique because it needs no special winches or cables and permits deployment of multiple pumps. It appeared to us to be the most practical method for collecting both dissolved and particulate phases taken from large sample volumes, without depth limitation, for the measurement of thorium and protactinium isotopes.

The relatively low flow rates achieved by our pumps are determined by the type, size, and porosity of the filters we must use for our analyses. The advantage of this is that the pump can be small and the drive motor relatively weak. As a consequence, power consumption is modest. The disadvantage, long deployment periods to collect samples of adequate size, is partly offset by the capability of deploying simultaneously a number of pumps on the same wire at various depths.

DESCRIPTION

Figures 1a, b, c and d show photos or schematics of the system taken from various angles to display all the components. With reference to these figures, the pumping system consists of: frame (A), on which is mounted pump (B) attached to motor housing (C); battery case (D); pump motor housing equalization bladder (L); and mechanical flow meters (E). These are best shown on Figure 1a.

Attached to the top of the frame are four filter holders (F), upper wire clamp (G), and wire retaining slot (H), all shown on Figure 1b.

Diametrically opposite the battery case is the combination battery/ programmer case (J), inlet manifold (K), and lower wire retaining slot (M) (Figure 1c).

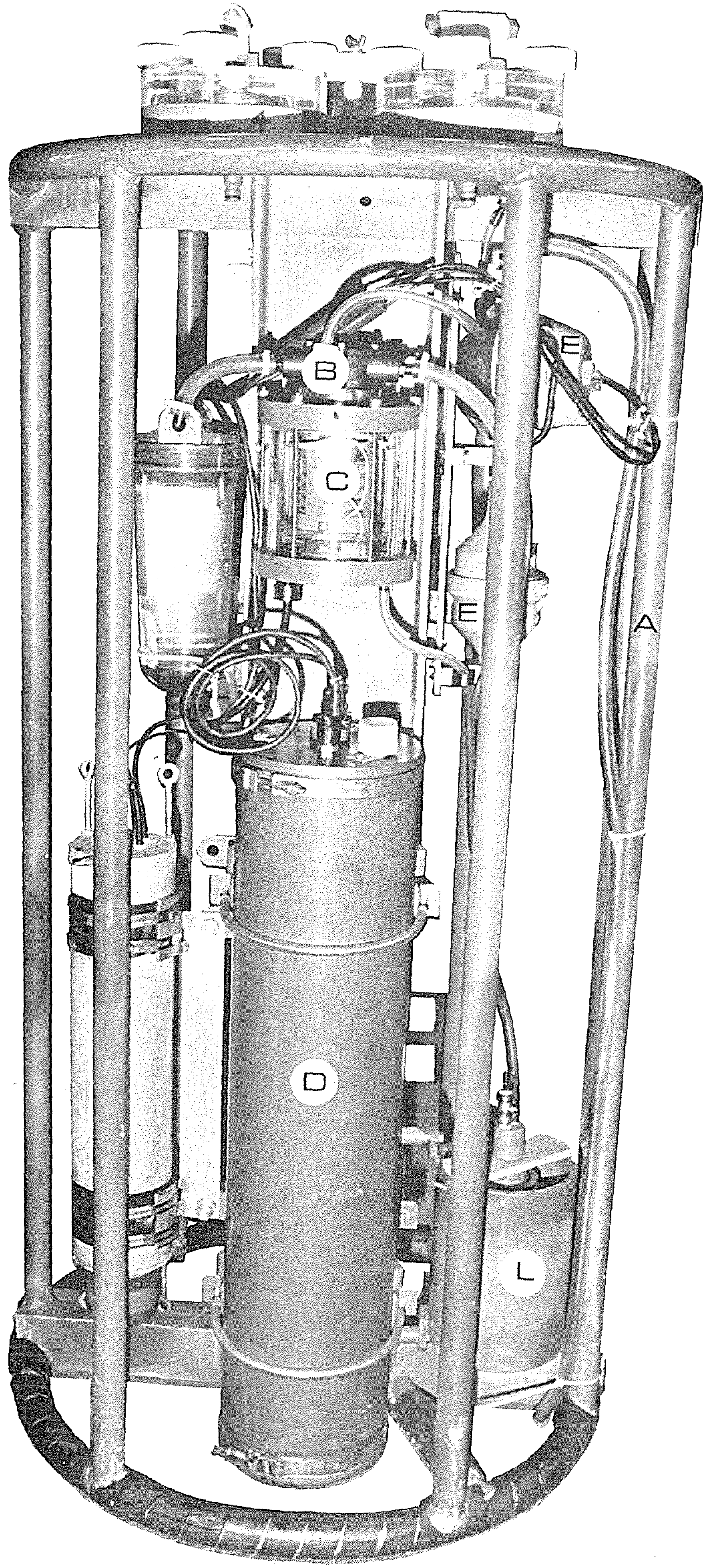
Figure 1d best shows pinger (O), three cartridge filter holders (P), and two of a number of sacrificial anodes (S).

The diagram of Figure 2 shows the path water takes through filters, manifold cartridges, pump and water meters. Figure 3 diagrams the electrical interconnections.

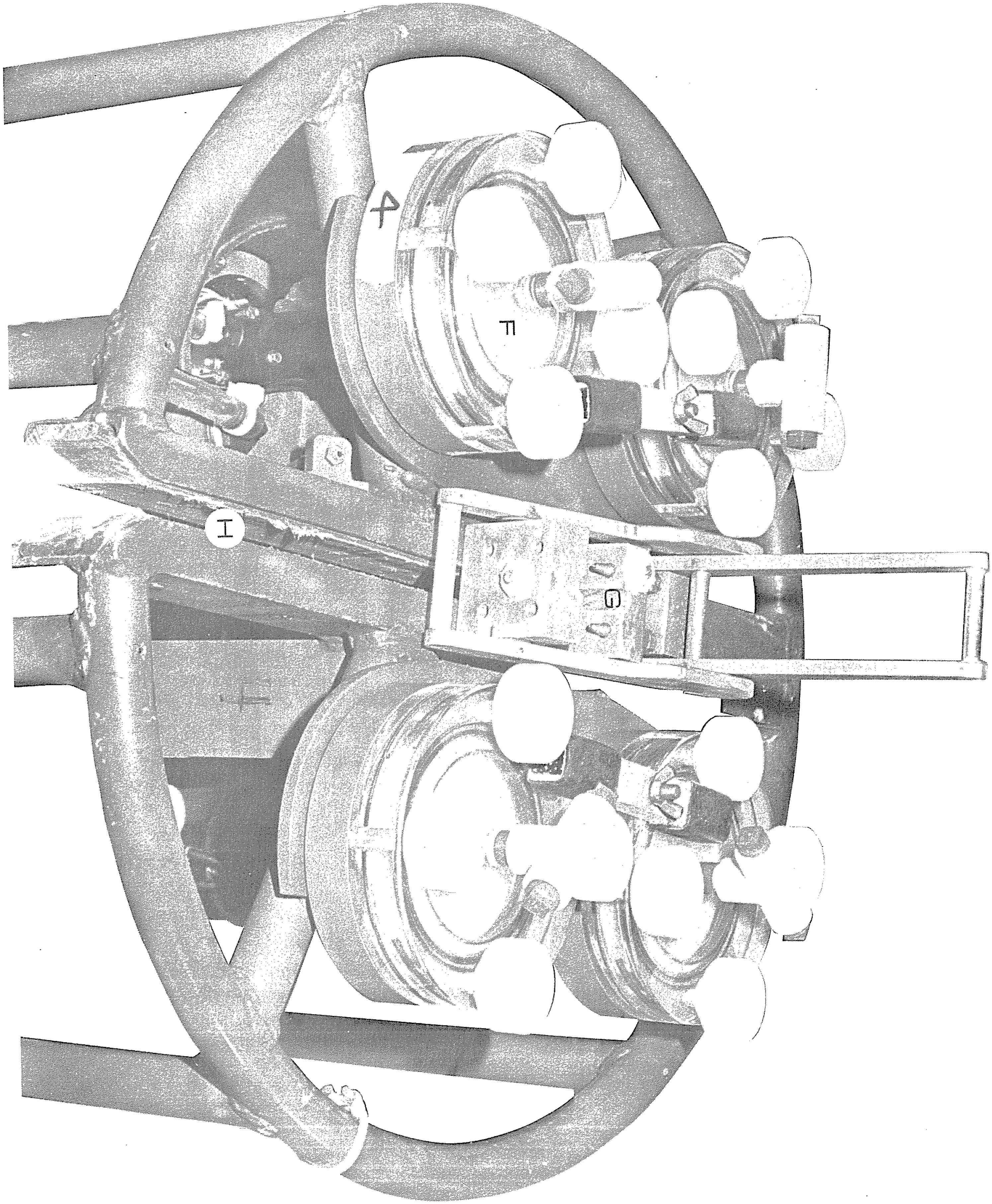
Frame

The frame is fabricated from 6061-T6 aluminum. The tubing of both the top and bottom rolled rings and the connecting uprights is 3.9-cm OD x 3.1-cm ID. Two sets of 7.5-cm American Standard channels are welded together to form a box section. Each end of each box is then welded diametrically across the top and bottom rings. A slot is milled half-way through these to the center of the rings to accommodate the ship's trawl wire. The inside of each box section is provided with oak chafing gear to minimize damage to the aluminum and its paint as the pumps are clamped to the trawl wire. The bottom box section is provided with a central socket which accommodates a wire stop when the frame is hung on the ship's wire.

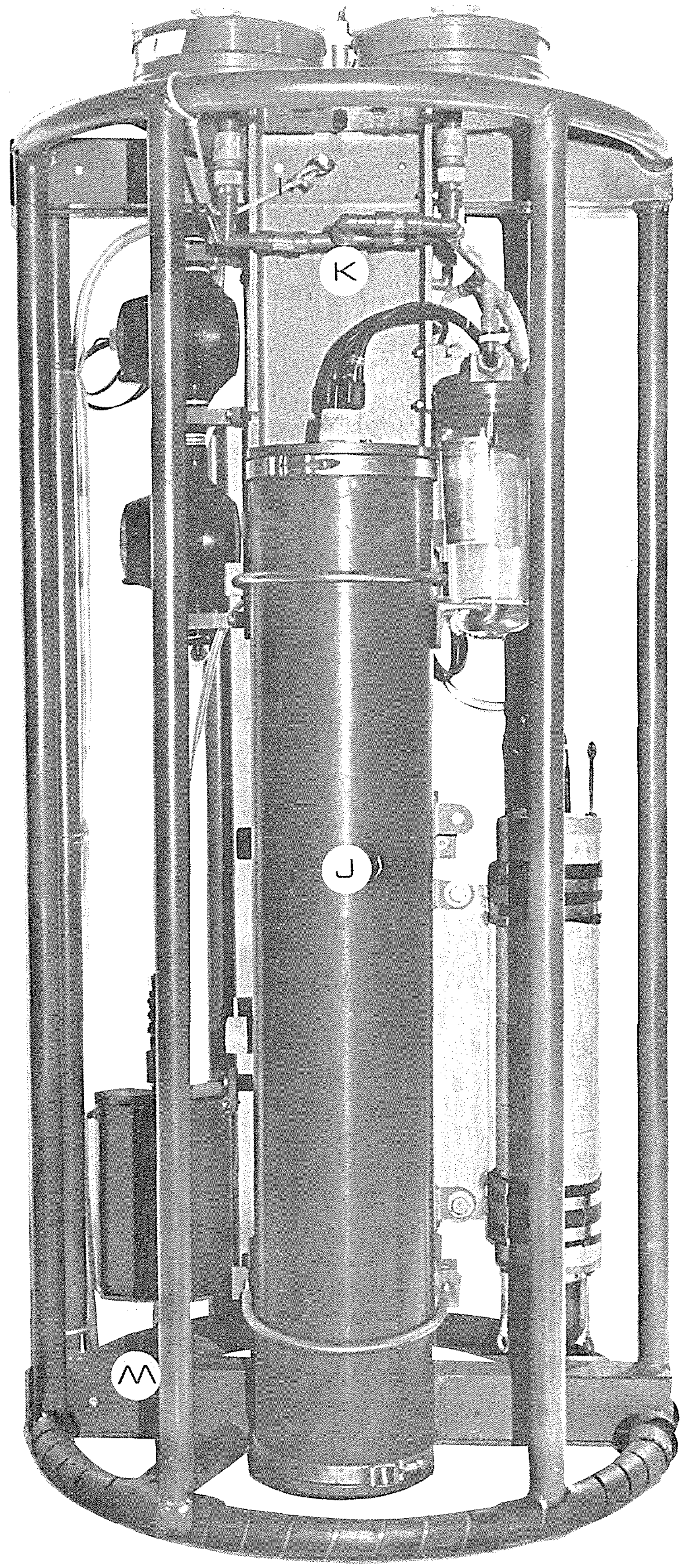
Two 20.5-cm channels arranged web-to-web and welded centrally to the top and bottom 7.5-cm channel boxes constitute the vertical "backbone" of the frame to which most of the components are attached. These are the main strength members of the frame; the primary function of the vertical tubes is to protect components when the package "kisses" the ship's hull in bad weather.



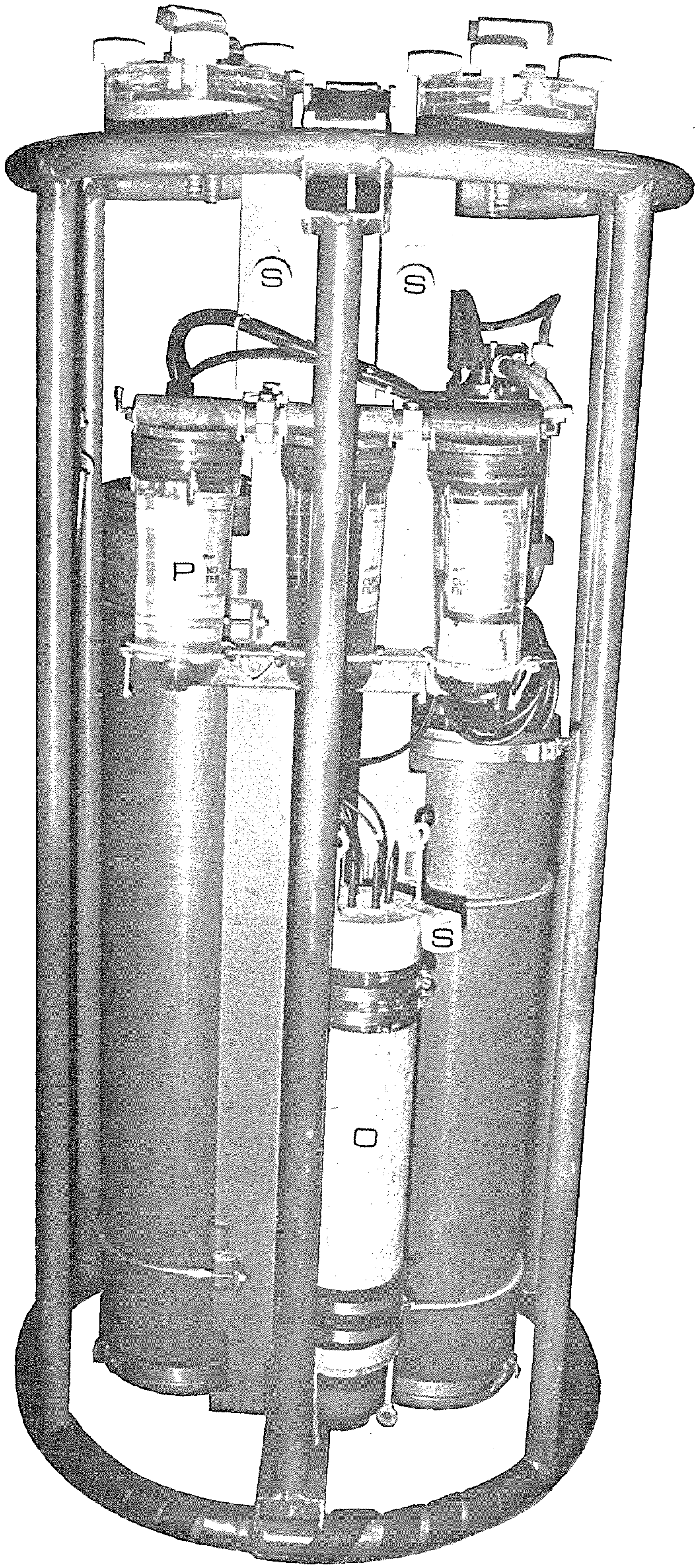
1a Pumping System - side view, pump side



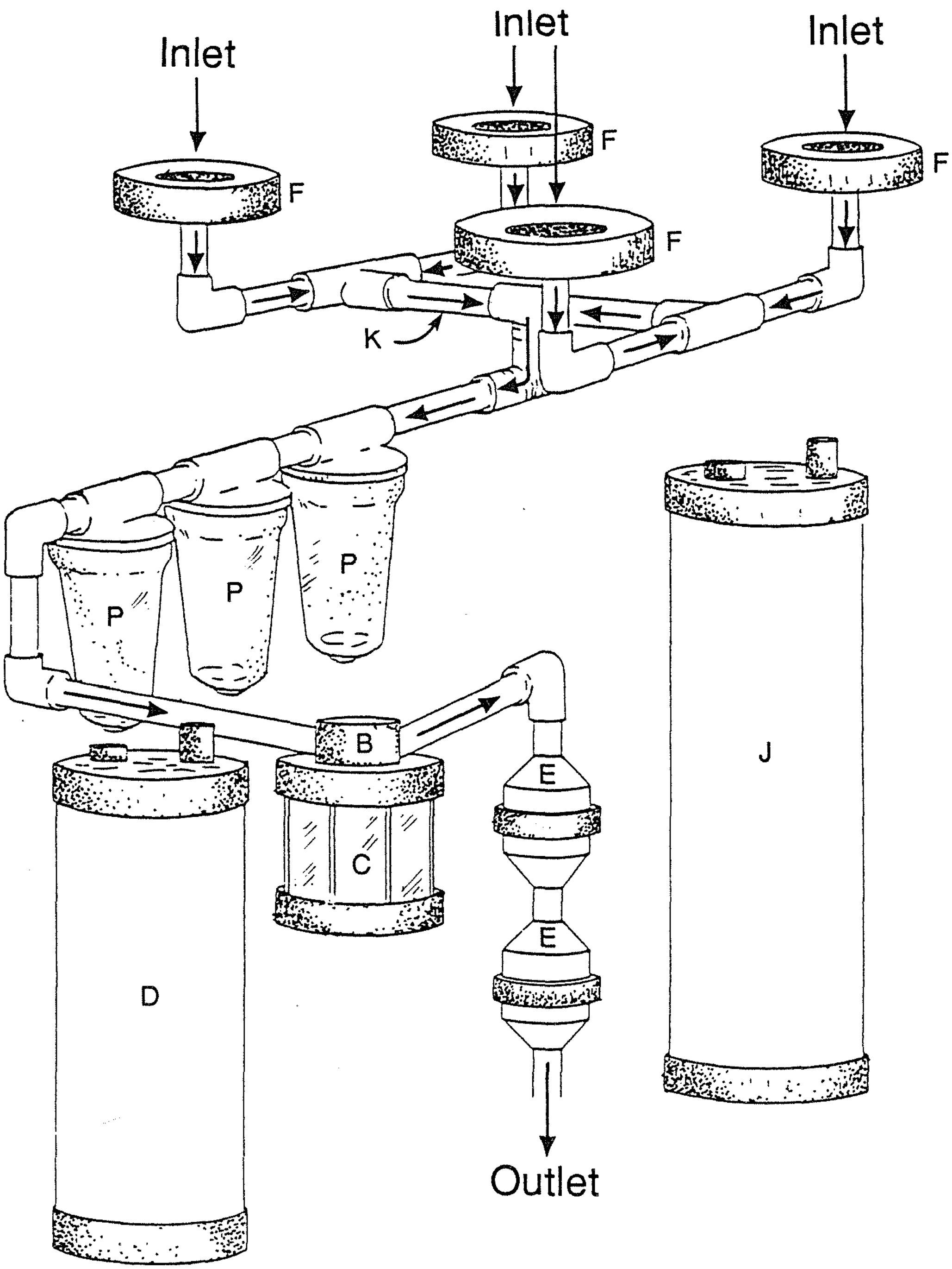
1b Pumping System - top view



1c Pumping System - computer, battery side

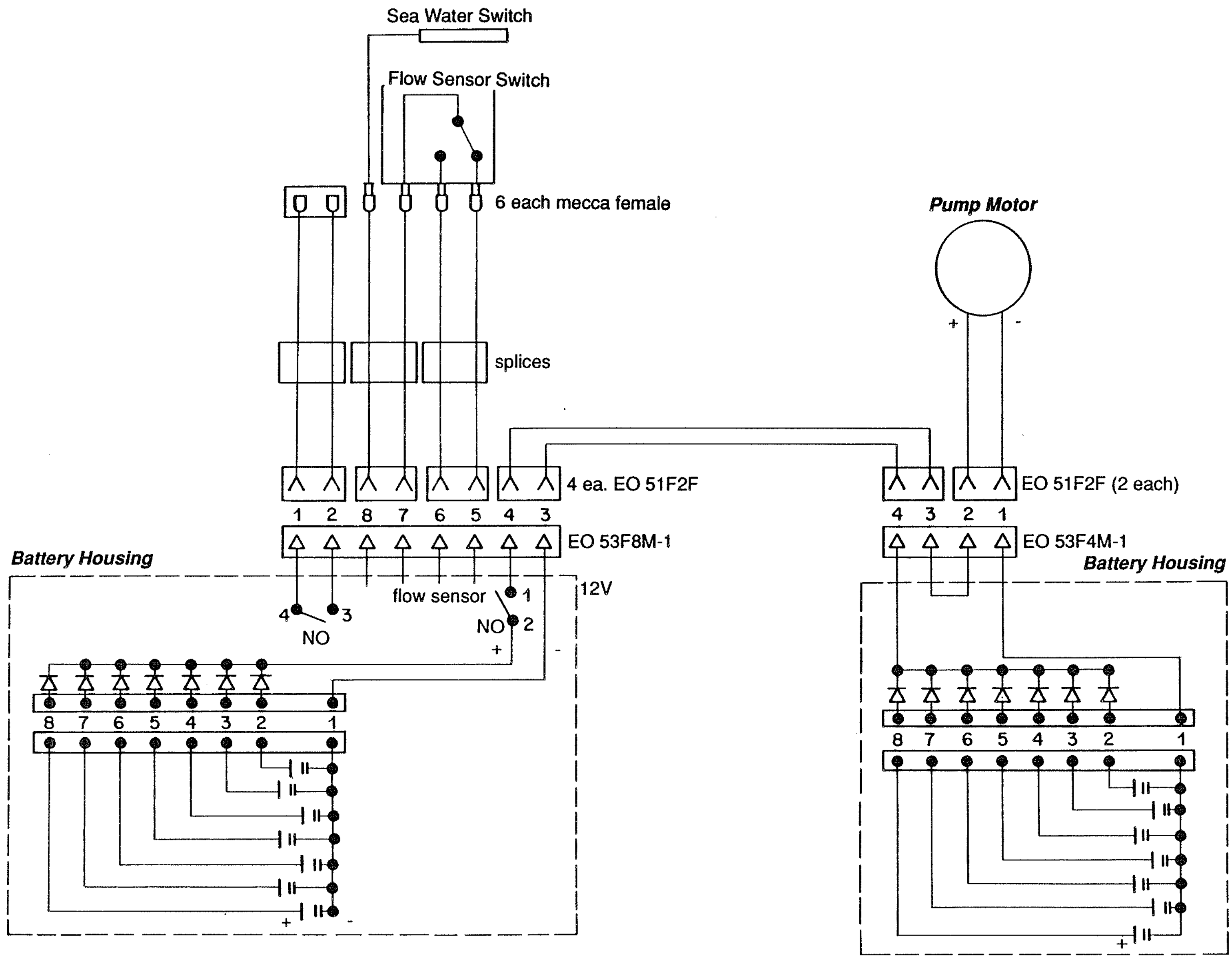


1d Pumping System - cartridge, pinger side



Arrows Deignate Water Flow
electrical Connections not shown

2 Schematic of Flow Path



3 Schematic of Electrical Connections

The frame is 1.7 meters high and 75 cm in diameter. With all components, it weighs about 200 kg. Frames are coated with an electrostatically applied epoxy finish. The base ring of each frame is wrapped with polypropylene chafing gear to facilitate sliding the frames on deck while protecting the paint. A number of zinc anodes attached to the frame in strategic places control electrolytic corrosion.

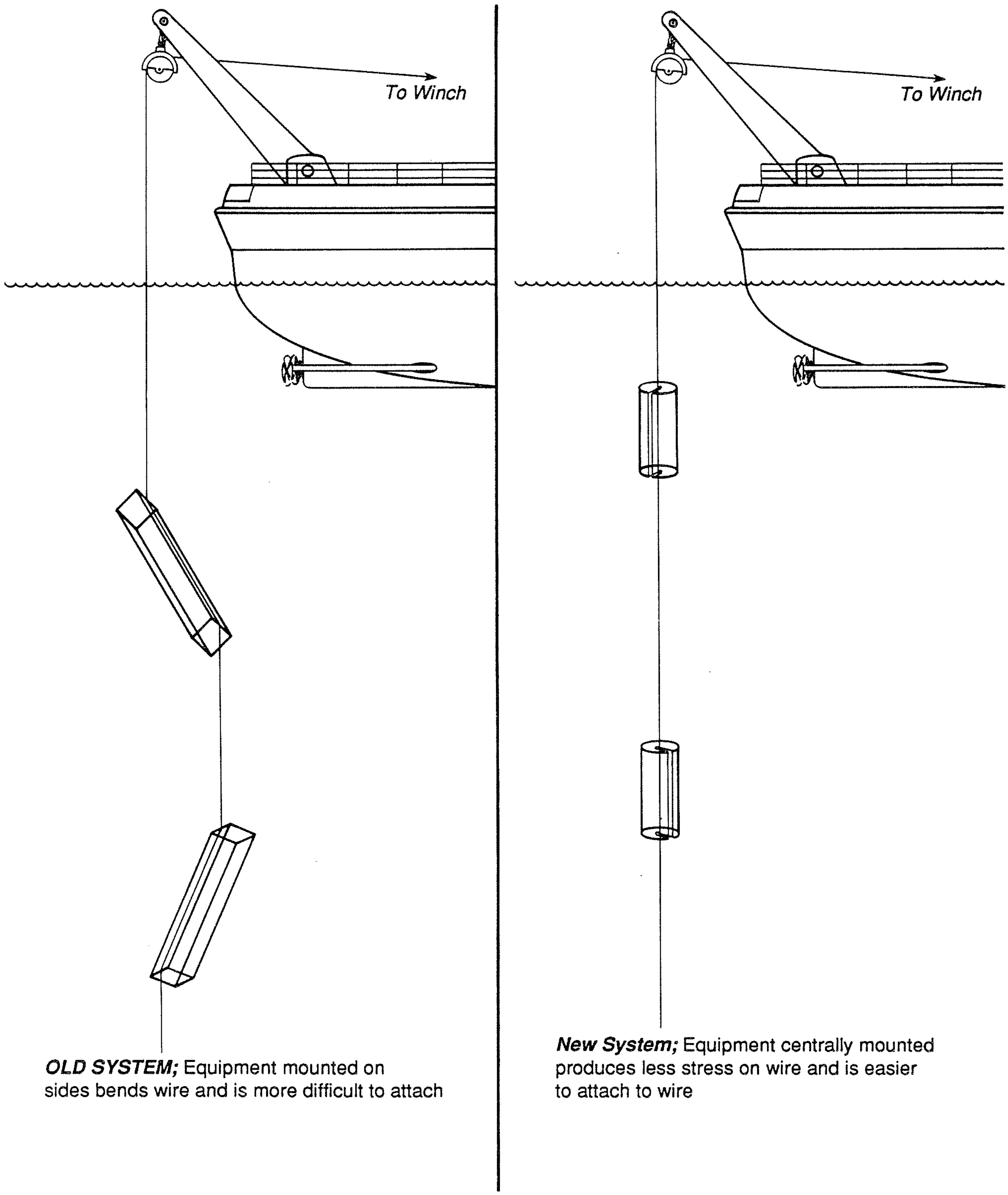
The frame was designed so that hydrodynamic drag while the pumps are raised and lowered is relatively low. "Kiting", especially when the package goes from air to water, is minimized. The diameter was made as small as possible at the expense of an ideal height; a tall person is needed to secure the upper cable clamp.

When deployed, frames are coaxial with, and component weight is concentrically disposed about, the ship's wire. This eliminates kinks at the wire clamps and minimizes undesirable stresses on both wire and instrument due to motion of the ship. Also, the smallest possible frontal area is presented in the direction of wire motion, again reducing drag. Figure 4 diagrams present and obsolete methods of attaching pumps to trawl wire.

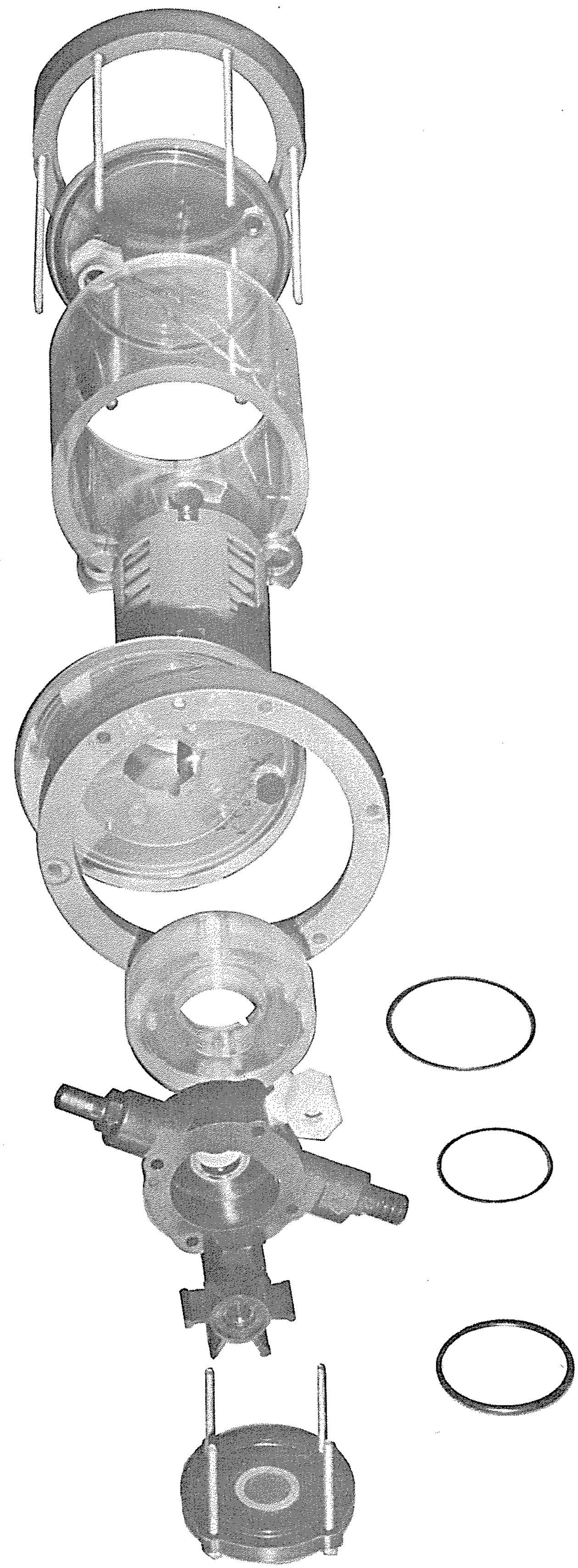
Pump, Pump Motor with Housing, and Equalization Bladder

These components form an assembly and are best described together. The photo of Figure 5a shows the assembly in an "exploded" layout. The pump (at the bottom of the photo) is a Jabsco Model 1700 used in industry to convey mildly corrosive liquids. The standard ceramic/carbon shaft seal furnished with this pump is used to seal sea-water out of, and oil within the motor housing. The impeller furnished with this pump is intended for relatively high delivery pressures, has ten veins, and is fairly stiff. For this application where high output pressure is not required, but where any reduction of friction is a bonus, a model 6303-0003 Nitrile impeller having six flexible veins was substituted. As a consequence, the drive motor works under lighter loads, especially when filters begin to clog. A hole was drilled in the epoxy body of the pump immediately below the oil side of the shaft seal so that air, which would normally be trapped there, could be bled from the oil-filled motor housing. A hose leading from a fitting in this hole is provided with a valve at its upper end. This is used when air is purged from the housing.

The pump is driven by an unmodified Yaskawa Electric TO6LB4 Mini Minertia™ 1/11 HP permanent magnet DC motor running in Bray oil. It was chosen for its low-speed, high-torque characteristics, both advantages when a standard motor is forced to run in oil. In this application it runs at about 500 RPM and draws about 2-3 amperes at 21 VDC when the pump is



4 Old vs New View of Pumps on Wire



5a Pump, Motor & Housing, exploded view

delivering 3-4 liters per minute. Increased speeds would waste power, because this is about the maximum flow through the filters employed; even a much larger pump does not increase the flow significantly.

The motor housing (best shown in Figure 5b) is 23 cm long and has a diameter of 17.5 cm. It is machined from clear acrylic tubing and is provided with o-ring sealed end caps, also transparent. PVC rings and stainless steel tie-rods clamp the assembly together to make the seal. A stainless-steel adapter shaft couples the pump impeller to the motor shaft. The pump housing is spaced away from the motor housing by a thick acrylic boss which accommodates the pump seal and matches the mounting holes for the pump on one end and the motor housing on the other.

The housing is larger than necessary to physically accommodate the motor so that carbon particle contamination of the oil due to wear of the motor brushes is kept dilute by a large volume of oil. Also, if a small amount of salt water leaks into the housing, it will normally not contact any vulnerable components.

The advantages of a transparent housing are numerous:

1. Air or gas bubbles in the oil are obvious and the ability to purge these from the housing is facilitated.

2. Small amounts of water are easily observed and eliminated.

3. Moving parts can be checked for proper functioning.

4. Carbon contamination of the oil can be monitored.

5. It is convenient to see the oil level when the housing is filled or drained.

Electrical connection is made with an Electro Oceanic 51F2F connector; the cable is sealed where it enters the housing with a Penn El 5975-608-463 stuffing tube. The bottom of the housing is provided with a fitting connected to a hose leading to the equalization bladder.

In order to compensate for the difference in compressibility between the Bray oil and sea water a 1066 cc polypropelene wide-mouth jar (Bel-Art Products #F10914) is used as an equalization bladder. This flexible reservoir is protected by an open-ended aluminum tube and mounted about one meter below the pump motor housing so that it is subjected to hydrostatic pressure there when immersed. In water there is a small positive pressure

5b Pump, Motor & Housing, assembled w / Pressure Equalization Bottle in the motor housing due to this mounting arrangement and the flexibility and rigidity of the bladder and the housing, respectively. This normally prevents water from seeping into the housing at the shaft seal. When out of the water, the opposite applies and there is a slight negative pressure in the housing because of these conditions. This tends to keep oil from leaking out. The equalization bladder is provided with a pet-cock so that the bladder and motor housing can be filled from the bottom while air is bled from the hose and valve attached to the assembly at the highest point above the pump housing.

The unit is shown assembled in Figure 5b.

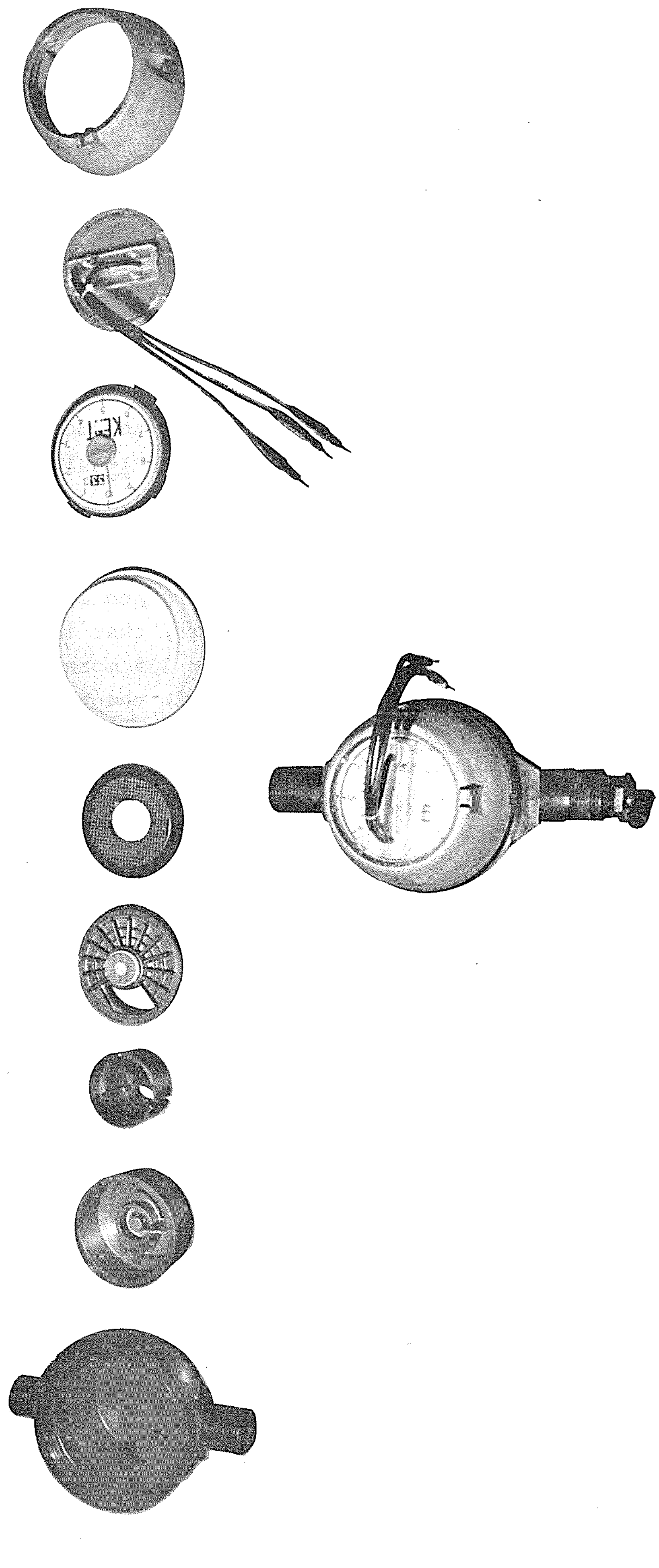
Flow Meters

Two Kent C-700 all plastic water meters are used to record the volume pumped and to sense the pumping rate (Fig. 6). These meters are designed to measure domestic water consumption but can be used submerged in salt water without any modification. The minimum flow rate which can be detected is about 0.5 liters per minute; the rotary piston driving the register stalls below this rate.

The meters are provided with a tell-tale attached directly to the piston shaft which turns at the rate of 10 revolutions per liter. When a suitably potted small magnet is secured to the tell-tale of one of the meters, a magnetic reed switch can be actuated twice per revolution. The switches are small and the glass housing in which they are hermetically sealed is pressure proof. Only the electrical leads need be insulated by sealing the whole switch in a plexiglass holder with RTV, and mounting the holder on the face of the water meter in close proximity to the rotating magnet. Flow rate is thus sensed by the switch: many closures equal high flow and vice versa. Switch closures are entered into a Sharp™ computer through a suitable interface, and software is provided to count and then record the closures periodically in the computer's memory.

A good record of flow rate is thus obtained when these numbers are read out of the computer memory after the pumps are retrieved. Moreover, total flow can be determined even if the flow meters stall due to low flow rates. As the filters become progresively more clogged with particulates, the flow rate decays quasi-exponentially. If flow rate is plotted versus time, the curve can be extrapolated beyond the point where the meter stalled to where the pumps stopped.

Two meters in series were originally used to ascertain that the small drag due to the magnetic switching had no appreciable effect on the proper



6 Water Meter with Event Switch

functioning of the meter. The second meter was subsequently retained because it was not in the way, there was no other use for it, and it was convenient to have a redundant spare.

Filter Holders and Manifold

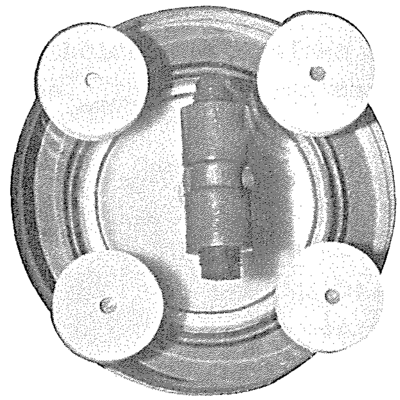
Filter holders are shown in Figure 7a,b. Four 142-mm filter holders per pump are used to obtain samples of adequate size and to allow the concentric attachment of the frame to the wire. A split of the total sample is obtained by designing the inlet manifold to the pump so that hose lengths and diameters leading from each filter are equal and the geometry of the manifold is symmetrical. The filter holders are clamped to the top of the pump frame, two at a time, with a toggle and wing nut.

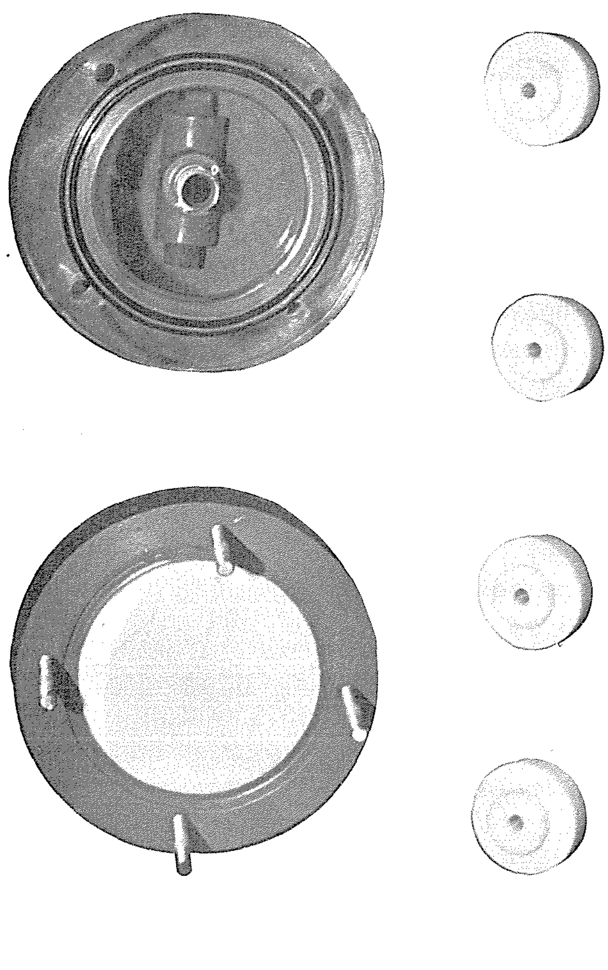
When Millipore Corp. stopped manufacturing 142-mm plastic holders, we took the opportunity to design and build our own, incorporating what we consider to be a number of improvements and cutting the cost by 70%: (1) the active area of our 142-mm filters, that is, the area covered by sample after a filter has been used, is over 33% more than a filter that has been used in a Millipore filter holder; (2) the top half of the holder is fire-polished plexiglass, allowing a visual estimate of the amount and sometimes the type of material on the filter and also assuring complete removal of water remaining trapped above the filter before the filter is removed from the holder; (3) a 7-mm thick sintered polypropelene disk replaces the perforated teflon-coated disc and stainless-steel reinforcement used by Millipore as filter support, allowing the increase in active area of the filter. Four knurled plastic knobs replace the aluminum knobs, which are not suitable for extended use in salt water.

A quick disconnect is at the outlet side of the filter holders so that they may be dismounted quickly and easily for processing the filters in the lab. A pipe tee in the inlet side keeps contaminants out. When not in use the inlet is sealed with plastic pipe plugs.

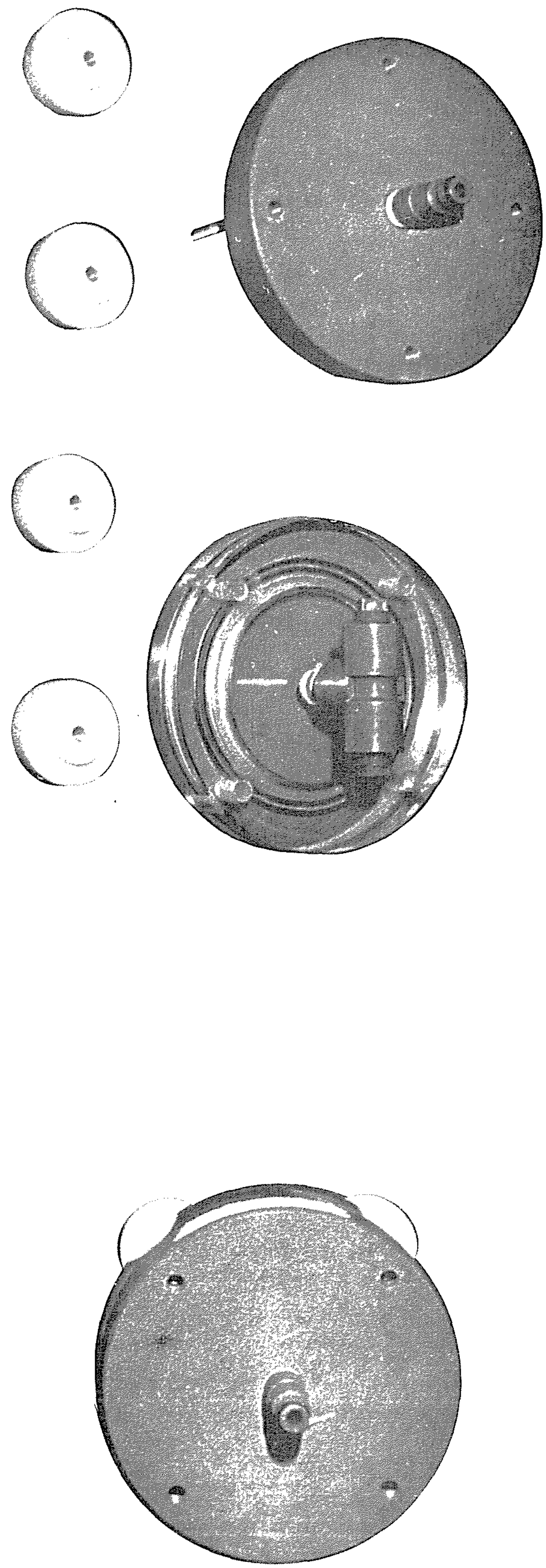
Adsorber Cartridges

In the flow path behind the particulate filters are three AMF CUNO Model 1M1 filter cartridge holders. The first of these is loaded with a standard AMF CUNO DPPPY or DPPPZ polypropylene filter cartridge to remove any particulates which may have passed the Nuclepore^{TM} filters. The remaining two are loaded with polypropylene cartridges which have been impregnated with manganese dioxide (MnO_2) in accordance with the procedure described in Appendix E.





7a Filter Holder, top view



7b Filter Holder, bottom view

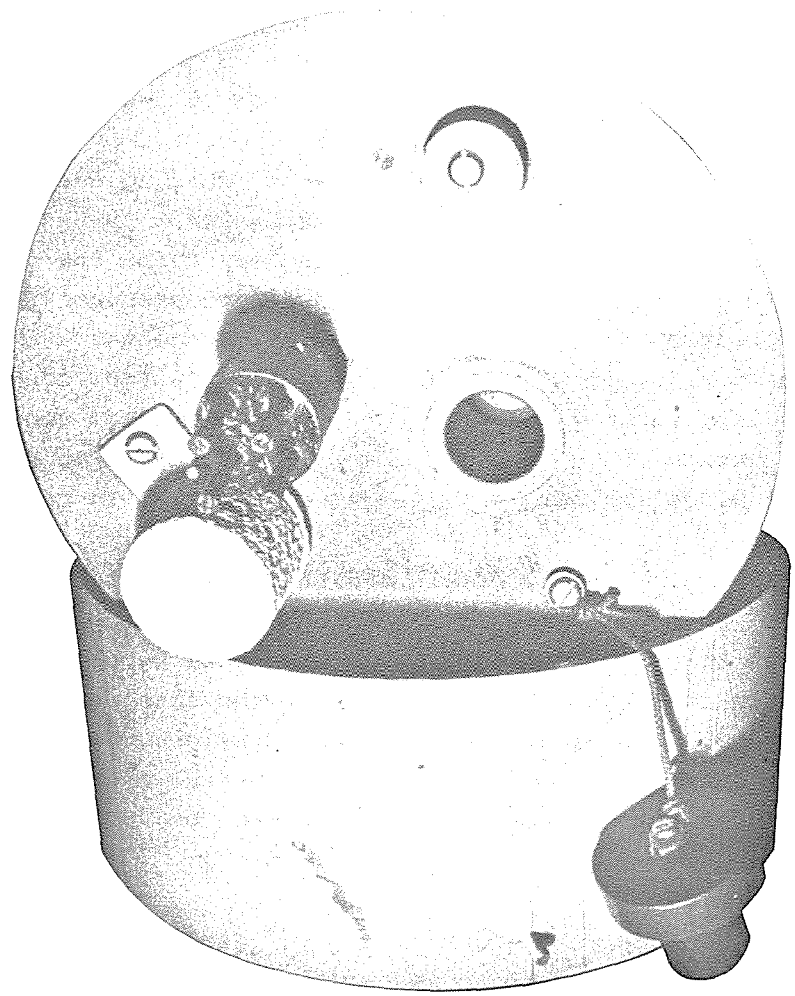
The three cartridge holders are joined together with 3/4" x 2-1/2" (1.9 x 6.4 cm) PVC nipples. These are run through two PVC clamps which are used to mount the three holders to the two central channels on the pump frame. To hold the lower end of the cartridge holders in place during deployment, three half circles are cut out of a piece of 5 x 5 cm aluminum angle iron. This angle is also fastened to the frame, and "bungi" cord is used to hold the cartridge holders in place. The "bungi" is used to facilitate removal of the cartridges between deployments.

Batteries and Housings

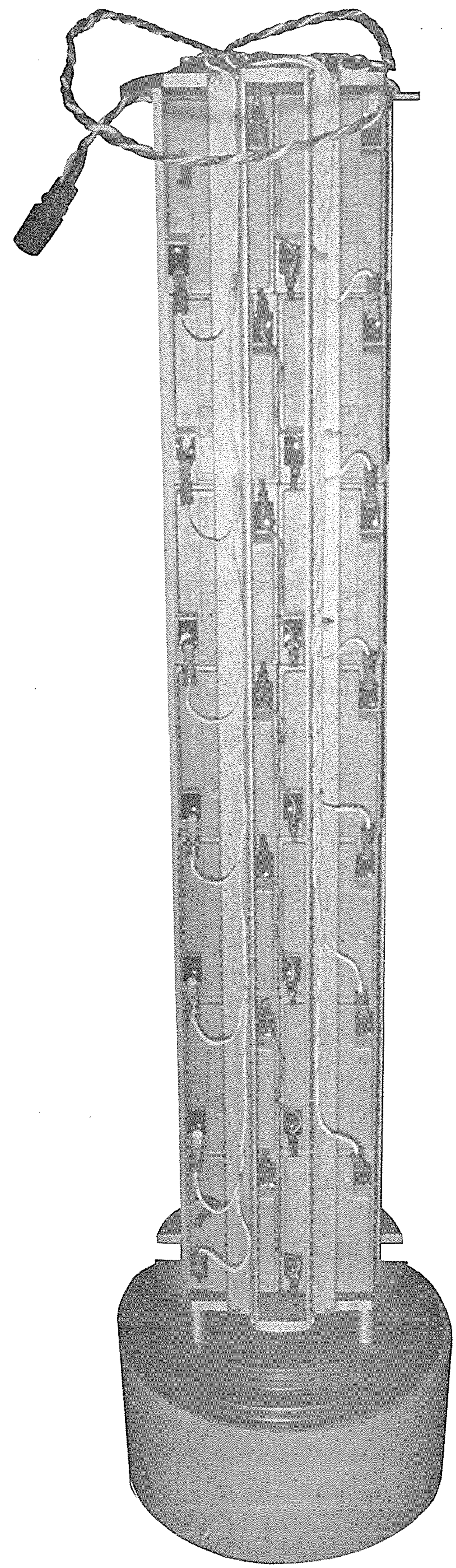
The two battery housings are machined from 20.3-cm OD x 1.9-cm wall 7075-T6 aluminum tube. The endcaps are made from 2.8-cm thick 7075-T6 aluminum plate. Both a high and a low pressure cap-ring seal are employed on the end caps which are fastened to the housings with V-band couplings. The battery stack is mounted on the lower end cap while the upper end cap shown in Figure 8a is machined to accommodate an overpressure relief valve, and one Electro Oceanics bulkhead type electrical connector. The upper end cap of the longer housing is also used to mount the Sharp controller and its associated electronic interface. Zinc sacrificial anodes are also attached to the outside of the upper end caps (Fig. 8a). The housings, end caps and blow-off plugs are hard-coat anodized to slow down corrosion.

The two pressure housings, complete with batteries and lower end caps are attached to the cradles, formally the two backbone channels of the frame. Two 0.6-cm thick 20.3-cm wide stainless steel U-bolts are used to hold each pressure case against PVC spacers on the flanges of the channel. A 0.6-cm stainless steel rod covered by a 1.9-cm nylon tube supports each pressure case held between the flanges of the central channels. This acts as a base support for the battery cases, which can be removed easily if necessary.

An assembled battery stack can be seen in Figure 8b. Seven power sonics PS1282S batteries are wired in parallel. They are diode protected during charging (3AF4) and discharging (F6) to prevent shortcircuiting of the batteries. They are mounted in a frame made of 6061-T6 aluminum angle and flat stock. The frame was designed to facilitate changing batteries. Nylon pads attached to the base on the back of the battery stack are used to slide the stack into the pressure housing. Stacks are mounted to the lower end cap with four 1/4-20 screws on 2.5-cm aluminum standoffs.



8a Upper End Cap, battery housing



8b Battery Stack, mounted on lower end cap

Electronic Computerized Interface Package

The pumping system is designed to take samples at a discrete depth. This is accomplished with the use of a computer based electronic interface which turns the pump on and off at specific time intervals.

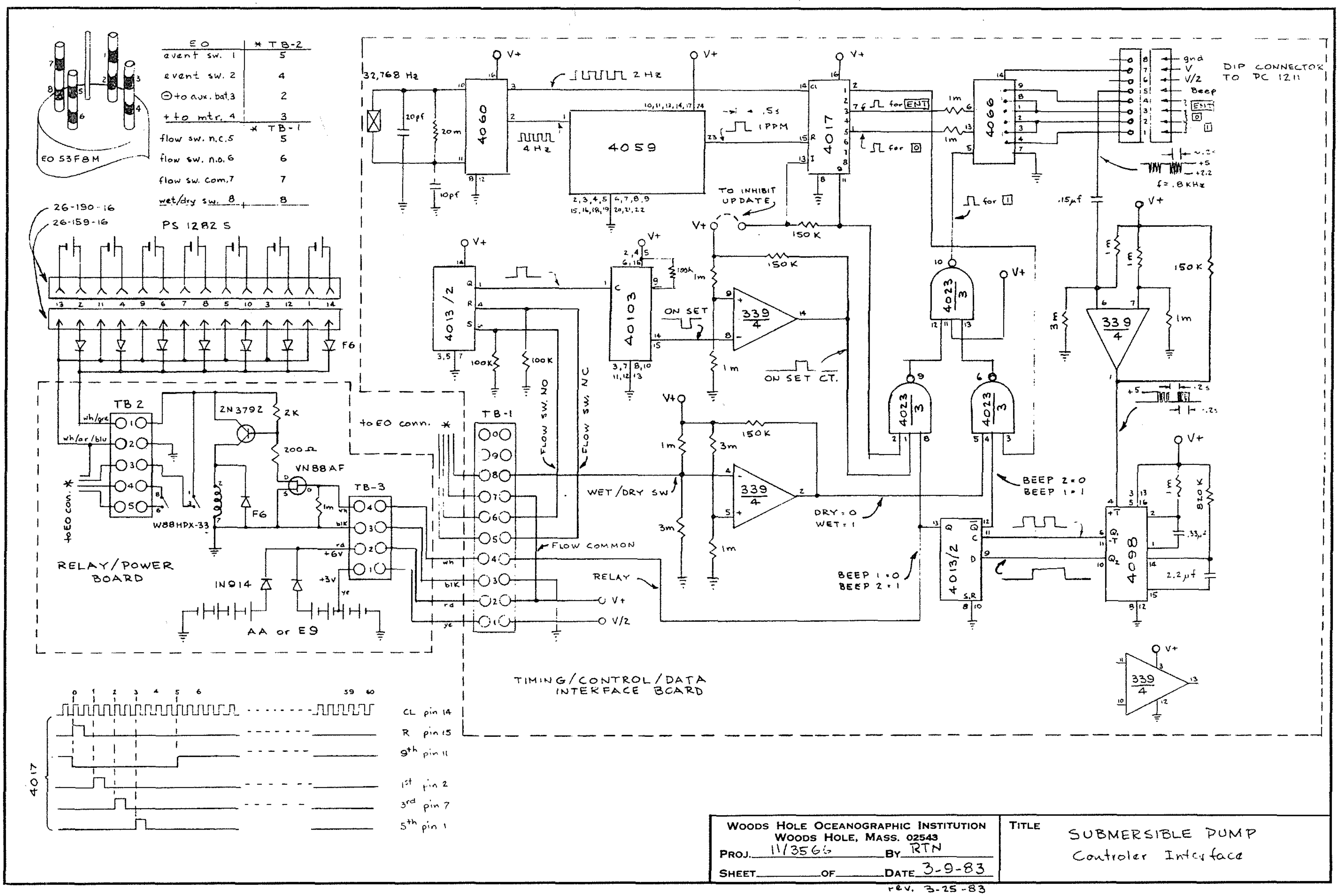
The heart of the timer control package is a Sharp PC1211 pocket computer with 16K memory capability. This has been slightly modified by hard wiring an external plug to the key pad and battery contacts of the PC1211. Wire connections for input/output are as follows: 1) battery + V; 2) battery + V/2; 3) battery ground; 4) "beep"; 5) "enter"; 6) "0"; and 7) "1". These connections are attached to a miniature 8 pin edge connector for communication to the timer/control/data interface board.

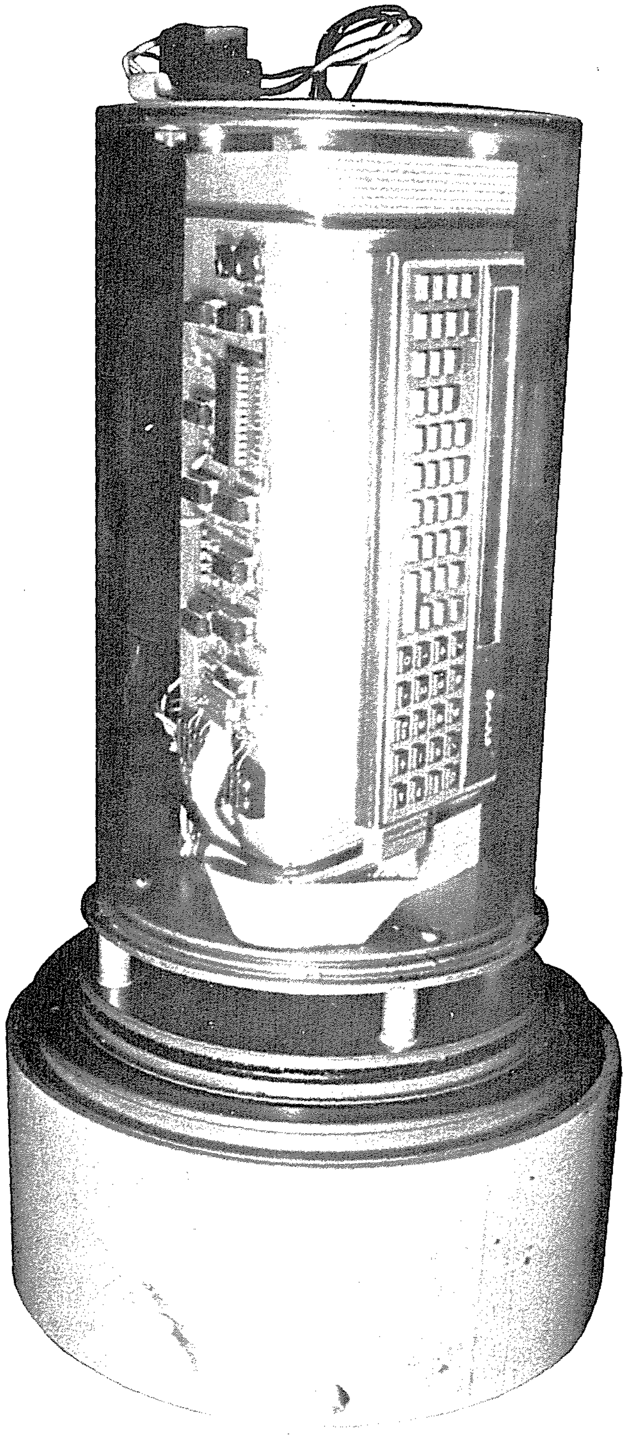
The interface board's many functions include providing the time base for clock entries to the PC1211, receiving and transmitting signals from the flow meters, providing information on the wet or dry condition of the pump frame and switching the power relay on command from the PC1211. The complete electronic circuit is shown in Figure 9.

The relay/power board is triggered by the interface board to make the final connection between the two separate battery stacks and the pump motor. These three boards are mounted together in a triangular configuration around three 1.25-cm diameter x 24.75-cm length aluminum rods. The Magnecraft #W88HPX-33 relay is inside the triangle. The aluminum rods are mounted to top and bottom aluminum plates 16.5-cm diameter and 0.63-cm thickness. These have been machined to accept a #160 O-ring, and to form a snug fit for a piece of 14-cm inside diameter x 0.64-cm wall x 26-cm length plexiglass tubing, mounted to the upper end cap for the longer pressure housing with three 0.63-cm x 3.8-cm long screws through 2.5-cm long aluminum standoffs. The plexiglass tube is used as a rain shield, since the electronics package is removed from the pump house after each deployment (Figs. 10a,b).

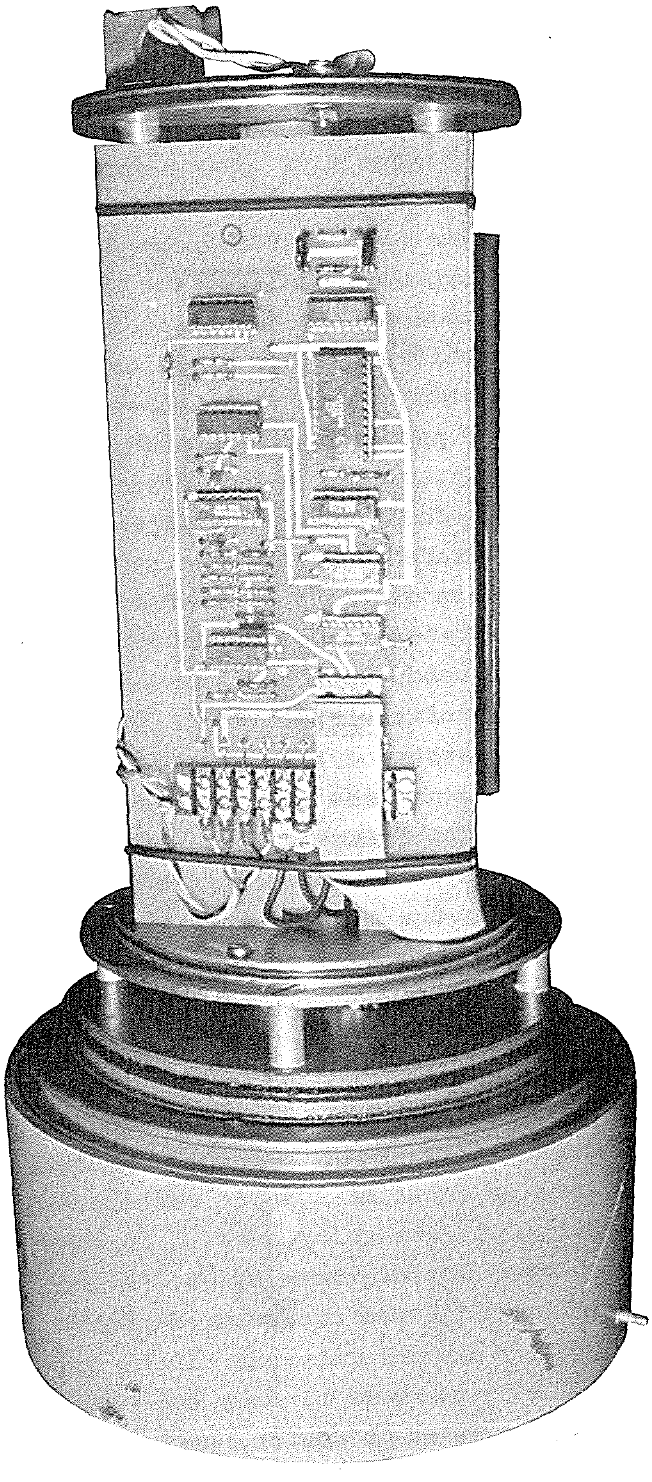
In operation, before each deployment, the interface and PC1211 pocket computer are turned on. A voltmeter is used to verify that clock pulses are being sent to the PC1211 and that flow pulses (artificially induced by a normally open/normally closed switch) are being properly received by the interface. The PC1211 is then programmed with the essential information for the cast. Prompts from the display on the PC 1211 request the information for cast "ID", delay time and pump time. The cast ID is two 7-character codes to identify date, cruise, pump number, depth, or any other relevant information.

9 Schematic of Computer Interface & Control Circuits





10a Controller Module, computer & interface sides



10b Controller Module, interface side

The "delay" time is the time the computer must wait after receiving a "wet" signal before it signals the interface to turn on the pump. This time is usually the calculated time it takes to get that pump to its desired depth. It includes wire time and deck time. The pump time is how long a sampling period is desired. This must be less than 28.5 hours due to the limited memory capacity of the PC1211.

The time base of the interface is provided by a Statek Corp. 37,768 Hz timing crystal. This is then divided down to 1 pulse per minute to the PC1211 and to a quad, 3-input NAND gate (CD 4011) which blocks unwanted signals to the computer. After the PC1211 is programmed, it delivers a "beep 1" signal to the interface. This signal shuts off power to the relay board and blocks some signals to the NAND gate. The software now calls for the PC1211 to be in a hold pattern until it receives a "wet" signal. This "wet" signal is provided when a piece of copper braid, which is connected to interface power through the Electro-Oceanics-EO53F8M bulkhead connector is brought to the ground state by being immersed in seawater and "shorting" out to the pump frame. This signal is transferred through one of four op amps in an LM 339 and triggers the NAND gate to send a signal to the PC1211. At this point the computer starts counting one-minute pulses from the clock. At the end of the "delay" time, the PC1211 sends a "Beep 2" signal which reverses the state of 1/2CD 4013 flip-flop. This in turn frees up another section of the NAND gate and opens the computer up for inputs from the external flow-switch. This signal also turns on the relay control circuit and starts the pumping operation. During the "pump time", which is usually 10-12 hrs, the opening and closing of the flow switch which is attached to the flow meters produces pulses which are fed to the interface, where they are divided down, and every eighth count is fed through the NAND gate to the "1" digit of the PC1211 to be counted. Again, the memory limitations of the PC1211 prevent us from counting every switch closure. At the end of the "pump time", a "beep 1" signal is sent from the PC1211 to the interface, which shuts down the pumping process in preparation for retrieval back on deck.

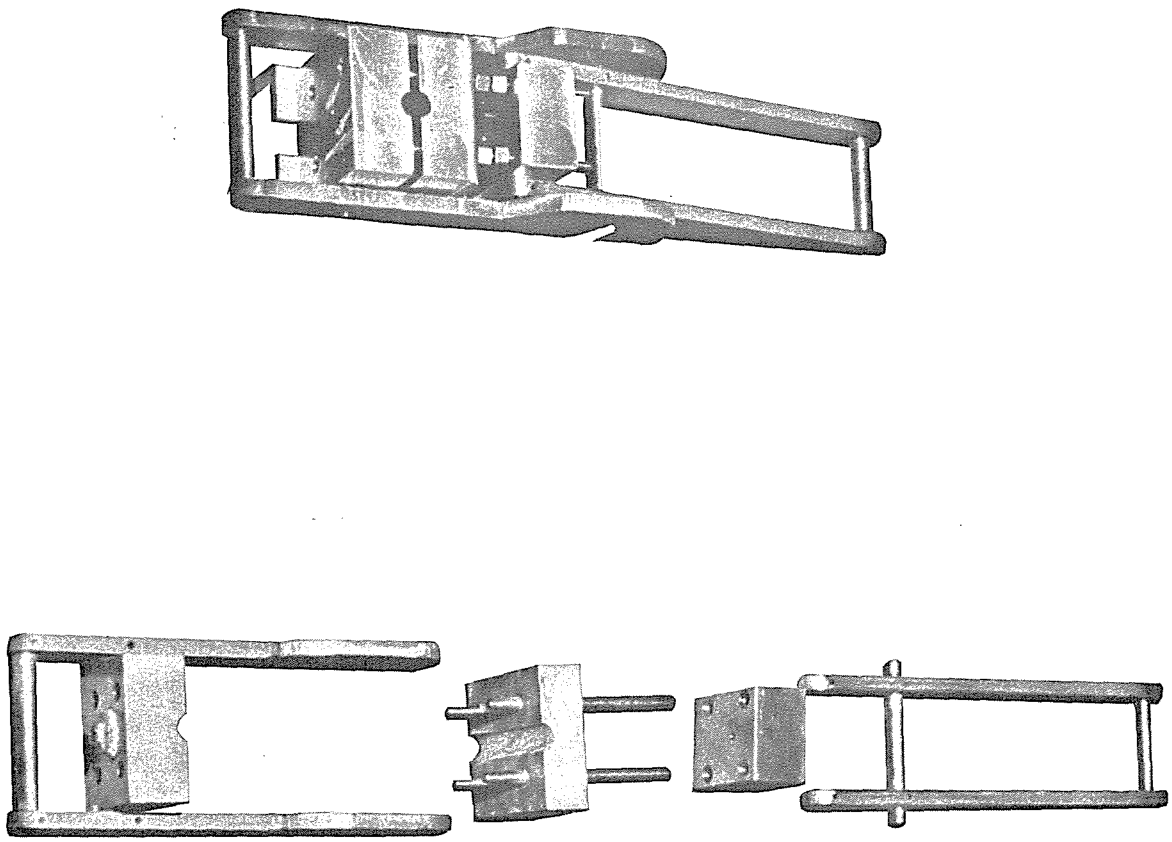
Upon retrieval, the record stored by the PC1211 contains the previously loaded sample headings and a record of number of pulses received by the computer during each 5 minute interval of the "pump time". The total number of pulses is also recorded. This provides us with a means of knowing not only how much water was processed, but also how the flow rate degraded as the filters clogged during the pumping cycle. The electronics for this system were designed by Mr. Richard Nowak, formerly of the Ocean Engineering Department at WHOI, and the software was written by Deborah Shafer of the WHOI Chemistry Department.

Wire Mounting Hardware

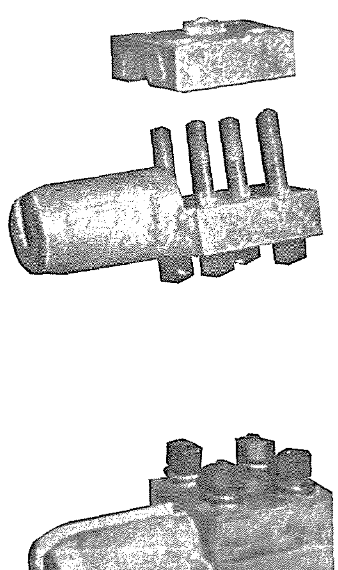
In an effort to make handling the pumps easier and reduce strain on the wire, the pumps were designed to mount concentrically around the ship's trawl wire. As mentioned in the description of the pump frame, there is a 6.3-cm socket built into the lower box section of the frame and a slot that runs to this from the outside edge. This socket is intended to mate with a wire stop clamp which has a 5-cm diameter x 8.25-cm length pin on the top of it. The wire stop is made of 6061-T6 aluminum and conprises three separate pieces of which two are welded together. These are two blocks 7.6 x 7.6 x 2.5 cm. One of these is drilled and tapped in four places to accommodate 1/2"-13 threaded rod. The other side is drilled in four places for a loose fit of the threaded rod. These two halves are then bolted together with a 1.6-mm shim between them and a 12-mm hole is drilled centrally between the two blades. The shim space allows for the clamps to squeeze down on the wire after it is attached. The 5-cm diameter round stock is then cut to length, and a 13-mm width x 3.2-cm depth round bottom slot is milled into it. One end is chamfered to make mating to the socket easier. This pin is then welded to the threaded half of the clamp blocks with the slot lined up with the slot in the block which was created when it was drilled. Four pieces of 1/2"-13 stainless steel threaded rod 8.3 cm long have stainless steel nuts welded to one end. These are then threaded through the pin half of the clamp from the back, non-slotted side, and are sealed in place with Loctite™ #271 adhesive/sealant (Fig. 11).

In operation, the pin half is placed around the wire and the second block is placed over the four bolts. Stainless steel lock washers and nuts are then threaded on to hold the clamp together, and the nuts are tightened with a pneumatic impact wrench delivering 12-13 kg-m of torque.

The upper wire clamp is made up of three component assemblies. Each assembly is made of 6061-T6 aluminum and stainless steel (Fig. 12a). The first assembly is the mounting block. This is a piece of 2.5-cm thick aluminum, 7.6 cm square. Four holes are drilled and tapped for a 1-cm threaded rod, and there is a half-round slot, 5.5 mm deep, milled into one side. Four pieces of 10-mm threaded rod, 11.5 cm long, are tapered about 10° for 2 cm at one end. Anti-corrosion grease is applied and these are threaded from the non-milled side of the aluminum block until the tapered portion protrudes from the front side. This assembly is installed through a similarly drilled piece of 4.6-cm aluminum angle, 4.5 cm wide, which is welded on the top of the pump frame so that the end of the slot matches up with the slot in the mounting block. Two nuts and one lock washer are turned all the way in on each rod to secure the block to the pump frame.



11 Upper Wire Clamp



12 Lower Wire Stop

The tension adjustment block assembly begins with a 3.2-cm thick aluminum block measuring 5.3 cm x 6.9 cm. Four 11-mm holes are drilled through to line up with the threaded rods on the mounting block. There is a 1.6-cm diameter hole slightly off center and horizontally across this block into which a 1.6-cm outside diameter x 1.3-cm inside diameter stainless steel sleeve is pressed. A clamp handle made up of 1-cm x 2.5-cm stainless steel flat stock is attached through this sleeve with a piece of 1.3-cm diameter stainless rod. The handle is made of two pieces of the flat stock joined together by stainless rod at each end and has a thick piece of stainless rod 6.4 cm from the block end of the handle. This thick piece extends beyond each side of the handle by 1 cm. The handle is 7.6 cm wide and 26 cm long. It is attached to the back end of the mounting block pins and fastened loosely with four nuts and lockwashers.

The third assembly, called the clamping block, is also made up of 3.2-cm thick aluminum and measures 7.2 cm x 7.6 cm. There are four 8-mm holes drilled through and countersunk on one side. These line up with the pins on the mounting block, and there is a matching 5.5-mm deep half round slot milled in its face. Another 1.6-cm hole is drilled horizontally through the block and a stainless sleeve is pressed into place. A clamp hook is again made up of pieces of 1-cm thick x 2.5-cm wide stainless steel flat stock. Two halves are attached together by 1.3-cm diameter stainless steel rod. The space between the two halves is 7.7 cm. At the opposite end from the block, a 1.3-cm wide slot is cut at 30° angle to the side of each piece of flat stock and an additional piece of flat stock 10 cm long is welded to the opposite side. This welded piece is used to strengthen the hooked end.

Before deployment, this upper clamp assembly should be properly adjusted to hold securely. A small sample of the wire to be used should be obtained for this purpose. The wire should be placed in the milled slot of the mounting block and the clamping block should be brought into position around the wire. The fixed end handle is raised and the clamp hook is latched over the protruding ends of the 1.3-mm rod. The handle is then lowered and the arc of rotation should bring the clamping blocks together in such a way that firm pressure needs to be applied to swing the handle past the center line of its mounting pin. If it is too loose, the outermost nuts on the mounting block pins should be turned out to tighten the clamp. After the tension is set, the nuts holding the tension adjustment block in place should be tightened down to secure everything in place.

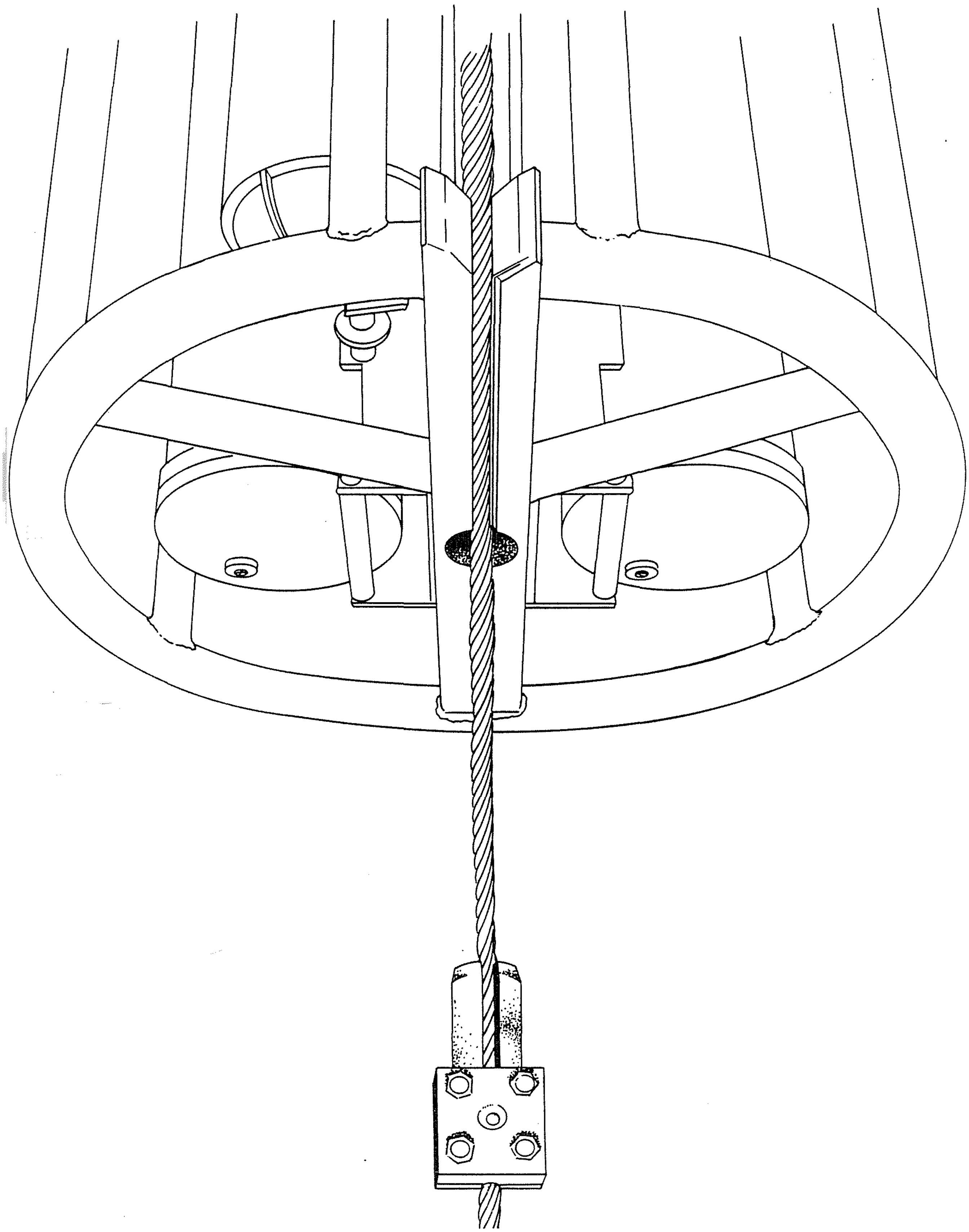
The procedure for handling the pumps on the wire is a great improvement over past systems of side mounting the equipment with book type wire clamps. The procedure begins by moving a pump frame close to the launch area and then attaching the wire stop block to the wire about 10 cm above deck level. The pump is then hoisted into the air either by ship's crane or air tugger with pulleys attached to the A-frame of the ship. The idea is to raise the pump as close to the trawl wire as possible to facilitate sliding it onto the wire. The lower slot in the frame is passed over the wire and the frame is then lowered down along the wire slot until the stop pin engages in the socket in the bottom of the frame. The pump is then twisted around to line up the upper slot with the wire and bring the pump into position. At this point a safety pin is pushed through the main web of the pump frame and across the wire slot to prevent the pump from falling off the wire from the ship's motion. The weight of the pump is allowed to rest fully on the wire stop. The upper clamp block and hook assembly is then slid around the wire and engaged in position on the clamp handle. The handle is buckled down tight, the lifting slings are removed, and the wire is lowered to the position of the next pump. This procedure is reversed to remove the pumps after deployment (Figs. 13a,b,c,d).

Inlet/Outlet Manifold

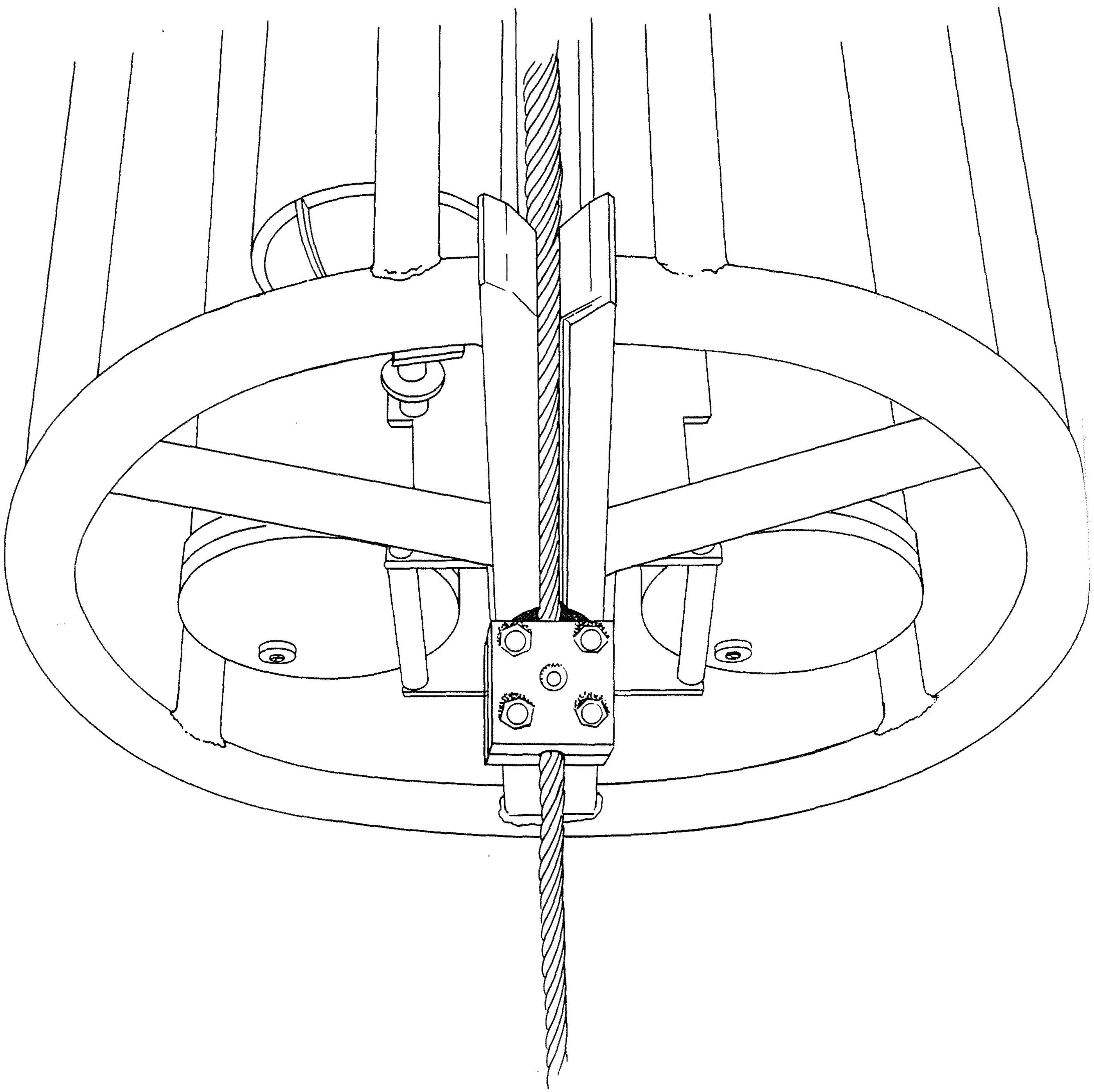
The inlet manifold is constructed to maintain an equal-length flow path from each of the four 142-mm filter holders. The manifold is made up of 1.3-cm I.D. x 1.9-cm O.D. Tygon^{TM} tubing. Gardena^{TM} quick connect hose adapters are attached to each filter. From these, tubing pairs off two filters on each side of the wire slot and the tubing joins together at a PVC Tee. The outlet ends of each side are then brought to another PVC Tee on the back side of the pump frame. The outlet end of this Tee is plumbed up to the first of three AMF CUNO 1M1 cartridge filter holders which are all tied together in series by 1.9-cm PVC nipples. The downstream end of the cartridge filter holders is connected to the pump inlet with polyethylene adapters. The Tygon tubing continues from the outlet of the pump through two Kent #C700 water meters and is finally exhausted through a length of tubing which runs to the bottom of the pump frame where it is furthest away from the sample water intake. The pump was placed downstream of the filters to eliminate any possible contamination from metal parts in the pump body or from possible leakage of oil from the motor housing.

Telemetering Pinger Option

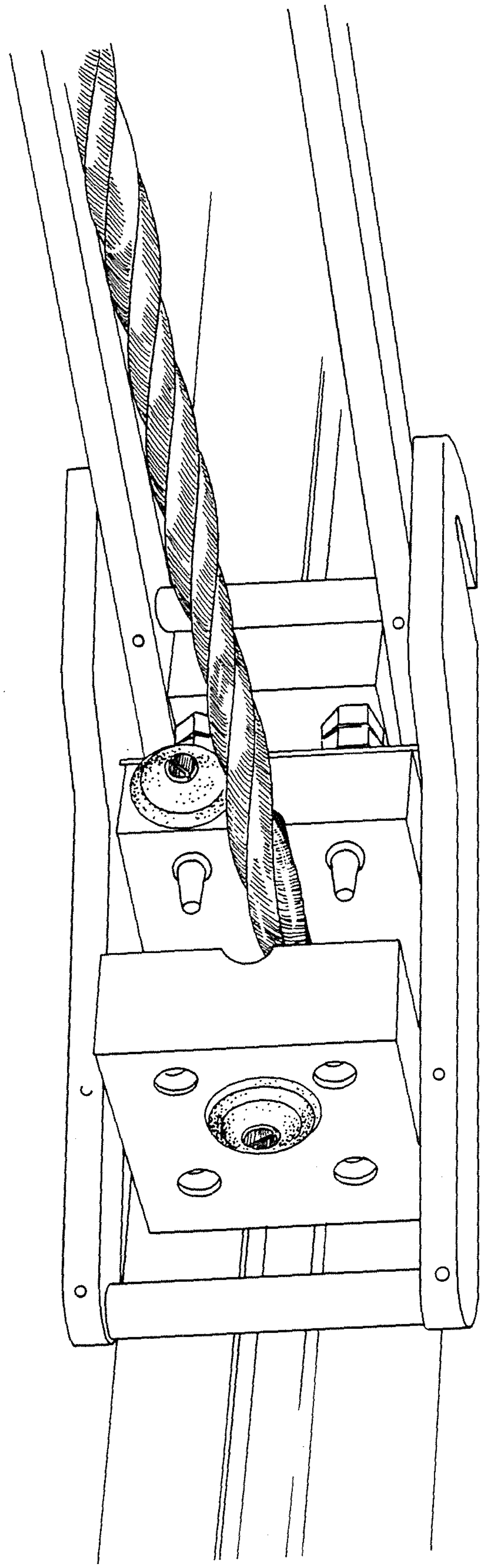
The Magnecraft #W88HPX-33 relay mentioned in the electronics interface section is a double-pole, double-throw relay. Since only one pole of this relay was used to switch power to the pump, the other side is available in the event that the use of a telemetering pinger is desired. Outside electrical connection to the relay is made through the Electro-Oceanics EO53F8M Bulkhead connector. Two contacts are closed together when



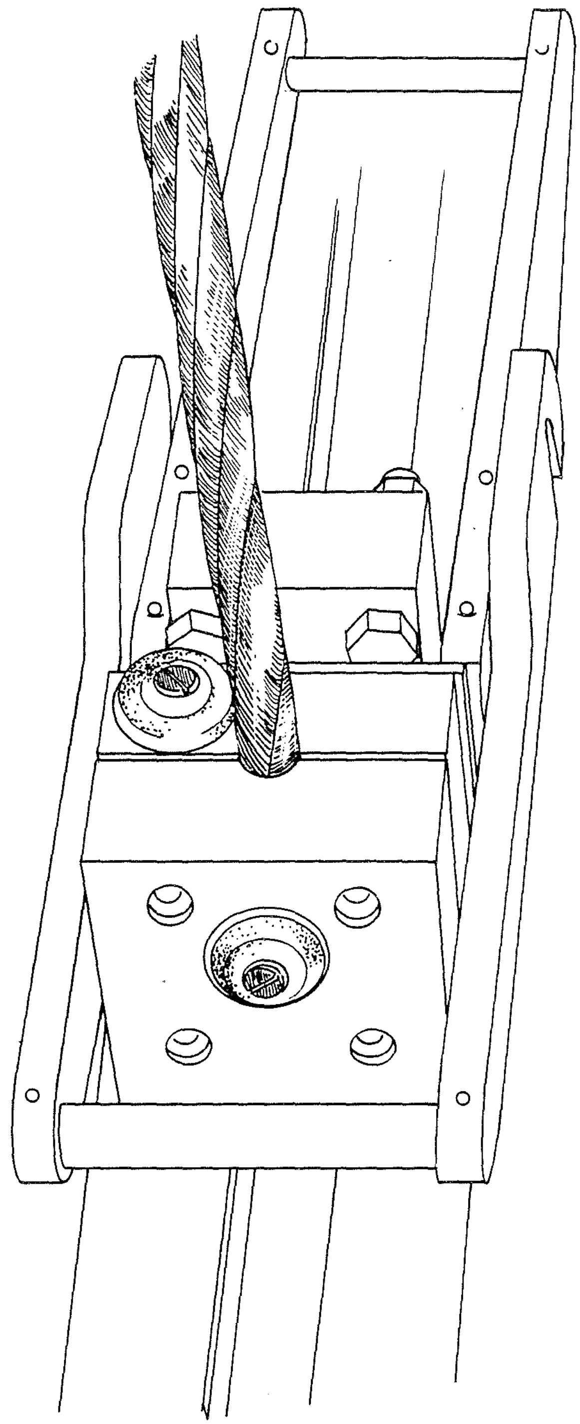
13a Pump Positioned Above Lower Wire Stop



13b Pump Supported by Wire Stop



13c Upper Wire Clamp, open possition



13d Upper Wire Clamp, clamped on wire

the pump turns on, and contact is broken when the pump turns off again. Pingers can be turned on or off or the pulse frequency could be changed by this switch closure depending on the electrical configuration of the pinger model used. This switch closure is also available to turn on or off any accessory equipment which might be added to the pump frame that has its own power supply and draws less than 10 amperes of current. The operation of the accessory equipment will then be synchronized with the operation of the pump.

PERFORMANCE

The pumping systems have performed exceptionally well over the past six years. They have proved to be very reliable with few serious mechanical or electrical problems. The problems that have occurred were mostly associated with wearing out or fatiguing of the plugs on the Electro-Oceanic cables. This problem usually becomes evident when one of the pumping systems fails to operate, and a specific cause cannot be determined. Replacing these power cables will often solve the problem. Other problems are more associated with human error while assembling the pump prior to deployment. The pumps have been deployed in everything but the worst weather, and have taken the beating very well. They consistently deliver 1,000-3000ℓ of sample, depending on how heavy the particulate load is in the water being sampled, over pumping times of 8-10 hours.

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APPENDIX A: PARTS AND MATERIALS LIST

Parts List

Batteries: Rechargeable, sealed, gelled electrolyte. 12 volt, 8 ampere-hour. Fourteen needed for each pump. $33.95 each on 2/10/89. Power Sonic PS-1282S, Power Sonic Corp., P. O. Box 5242, 3106 Spring Street, Redwood City, CA 94063, (413) 364-5001.

Caps, Pressure Case Guard: Used to cover open cases when on deck. #7-75. $.83 each on 8/3/82. Aydin Molded Devices, P. O. Box 4001, Santa Monica, CA 90404, (213) 630-4252.

Coating, Hard Anodized: $65 for 42-1/2" pressure case; $48 for 32-1/2" case. $6 for each endcap on 5/12/82. Duralectra, 61 North Avenue, Natick, MA 01768, (617) 653-7860, or local protective coatings company.

Coating, Powdered Epoxy: Electrostatically applied to frame components. $155.00/pump frame on 10/1/82. Teknicote Inc., 396 Roosevelt Avenue, Central Falls, R.I. 02863, (401) 724-2230, or local protective coatings company.

Connectors, Battery Stack: Amphenol Series 44, 3-pin waterproof connectors. #44-104-10003-02 receptacle, 2 each/pump @ $.83. #44-103-10003 plug, 4 each/pump @ $.78. #44-105-10002-02 boot, 1 each/pump @ $1.98. #44-102-14145-100-101 socket, 8 each/pump @ $19.09/100. #44-102-1414P-100-101 pin, 6 each/pump @ $9.00/100. Pricing as of 4/5/85. Gerber Electronics, 128 Carnegie Row, Norwood, MA 02062, (617) 769-6000, or local electronics supply warehouse.

Connectors, Underwater: Electro Oceanics.

1 each 53F8M-1. 4 pin, 8 contact, male bulkhead connector; $73.00.

1 each 53F4M-1. 2 pin, 4 contact, male bulkhead connector; $50.00.

3 each 51F2F-1. 2 contact female pigtail; #16.00 each (add 1 each if telemetering pinger is used).

1 each 51F2F-1 on each end of 5′ total length cable. Contact 1 to contact 1, contact 2 to contact 2, $49.25 each.

Pricing as of 9/10/85. Crouse-Hinds Electro, 7022 Alondra Boulevard, Paramount, CA 90723, (213) 636-9321.

Connectors, Underwater MECCA: 4 each male and 4 each female singe pin pigtail connectors. Approximately $8 each (add 2 females if pinger is used). Carl Leuders & Co., P. O. Box 30, Needham, MA 02192, (617) 449-0435.

Coupling, Quick-Connect Filter: Gardena #69271, repair type quick connect coupling $3.89 each on 9/7/82. 4 each/pump. Gardena Inc., 10260 S.W. Nimbus Avenue, Building MI, Portland, OR 97223, (503) 784-2620.

Coupling, V-Band: #5322K-806-2A Voss Industries, Inc., 2168 West 25th Street, Cleveland, OH 44113. $56.40 each on 4/4/89.

Crystal, Timing: Statek Model #SX-IN, 32,768HZ, Calibration A. $7.05 each on 7/15/80. Statek Corp., 512 N. Main Street, Orange, CA 92668, (714) 639-7810.

Filter, Cartridge: AMF-CUNO Microwynde Model DPPPY, wound polypropylene DPPPY, $4.88 each in 1982. MWM Co., 11 Newbury Street, N. Quincy, MA 02171, (617) 328-1920 or local distributor of filter products.

Filter, Particulate: 1.0-µm pore-size, 142-mm diameter. Nuclepore Inc., 7035 Commerce Circle, Pleasanton, CA 94566, (415) 462-2230.

Filter Holders, Cartridge: AMF-CUNO Model 1M1 $46.10 on 4/4/89. MWM Co., 11 Newbury Street, N. Quincy, MA 02171, (617) 328-1920 or local distributor of filter products.

Filter Holders, Particulate: K&S Machine Co., 265 Pleasant Street, Rockland, MA 02370, (617) 328-1920, or local precision machine shop. $146.50 each on 9/2/82.

Filter Support, Particulate: 1/4" thick sintered polypropylene #F13639, $37.50/18"x18" sheet, enough for 9 filters. Bel-Art Products, 6 Industrial Park, Pequannock, NJ 07440, (201) 694-0500.

Flow Switches: Hamlin MLC-DT-186 magnetic reed switch with Hamlin H-33-606 magnet potted in General Electric clear silicone, $2.80/switch, $1.04/magnet on 3/13/86. Gerber Electronics, 128 Carnegie Row, Norwood, MA 02062, (617) 769-6000, or local electronics supply warehouse.

Flow Meters: Kent Model C-700, 3/4" x 3/4" female pipe thread, $61.05 each on 6/10/83. Kent Meter Sales Inc., P.O. Box 1852, Ocala, FL 32678, (800) 874-8710 or (904) 732-4670.

Motor, Pump: Yaskawa Electric TO6LB4 Mini Minertia, $176 on 8/12/82. Yaskawa Electric, 14811 Myford Road, Tustin, CA 926801, (714) 731-6841.

Oil, Pressure Compensating: Bray #3M626-2, $105/5 gal. in 1983. Bray Oil Co., 2698 White Road, Irving, CA 92714, (714) 660-9454.

Oil Reservoir: Bel-Art #F10914, 1ℓ capacity wide mouth polypropylene bottles. $14.50/6 on 10/15/84. Bel-Art Products, 6 Industrial Park, Pequannock, NJ 07440, (201) 694-0500, or local scientific supply warehouse.

Oil Reservoir Neck Seal: Molded from Dow Corning, 3110 RTV with standard cure catalyst. RTV was $13.39/16, and catalyst was $1.76 on 10/31/84. Brownell-Electro, 10 Linscott Road, Woburn, MA 01801, (617) 935-7826.

Plexiglass Tube: Computer rain shield is 6" O.D. x 1/4" wall - $15.64/ft. on 8/13/82. Motor housing is 5-3/4" OD x 3/8" wall - $44.28/ft. on 8/13/82. Cadillac Plastics, 269 McGrath Hwy., Somerville, MA 02143, (617) 666-8840, or local specialty plastics supplier.

Pressure Cases: 8" OD x .75" wall type 7075-T6 aluminum tube. $123.99/ft. on 8/17/82. Kilsby Tube supply, 4015 Westinghouse Blvd., Charlotte, NC 28210, (800) 438-3450.

Pressure Case End Caps - Blank Discs: 8-1/4" x 1-1/2" thick; type 7075-T6 aluminum. $25.75 each on 2/11/82. Peter A. Frasse & Co., 59 South Street, Hopkinton, MA 01748, (617) 435-6854.

Pressure Case and End Cap Machining: $60/end cap; $75/long case; $70/short case on 9/20/82. Oceanic Industries, 262 County Road, Monument Beach, MA 02553, (617) 759-2402, or local precision machine shop.

Pump: ITT JABSCO, Model #17000, $46 ON 10/2/84. Seal Assembly #96080-0280; stainless spring $22.30 on 10/2/84; impeller #6303-0003; nitrile or 6303-0001 neoprene, 8.75 on 10/2/84. JABSCO Products ITT, 1485 Dale Way, Costa Mesa, CA 92626, (714) 545-8251, or W. A. Kraft Co., 308 N. Harvard Street, Allston, MA 02134.

Relay, Power: Magnecraft #W88HPX-33, 10A Contacts, 12 Volt, 1.5 watt DPDT switch. Gerber Electronics, 128 Carnegie Row, Norwood, MA 020621, (617) 769-6000 or local electronics supply warehouse.

Rings, Frame Upper and Lower: Rolled to 30" OD from 1-1/2" OD x .125 wall, 6061-T6 aluminum tube; $16 each on 5/4/82. New England Ring & Flange, 480 Green Street, Cambridge, MA 02139, (617) 547-5508.

Stuffing Tube, Pump & Motor Housing: Size 1 Nylon Straight Type Federal Stock #5975-296-4092, $1.88 on 5/1/78; packing assembly, .296 ID, Mfg. Code #1C, $.89 each on 5/1/78. O'Neal Corp., 15 Exchange Place, Jersey City, NJ 07302.

Transformer, Battery Charger: Powerstat #1256, 30A capacity. Ast/Servo Systems, Inc., $209 on 1/20/83. 115 Main Road, Montville, NJ 07045-9299, (201) 335-1007 or (800) 922-1103.

Materials List - In-Situ Pumps Main Frame

Stock Item	Stock Size	No. of Pieces and Length	Amount Needed	Description
		6061-T6 Aluminum		
Channel	3x1-1/2x.20x.13	4x30"	10′	Ribs
	8x3x5/16"W	2x5′	10′	Backbone
	1x1x1/16"W	2x7.5"	15"	Filter Holders
	5x2x1/4"W	1x10"	10"	Motor Mount
Tube	1-1/2"ODx.125W	7x5′+2x8′	51′	Verticals & rings
	4"IDx.125W	1x8-1/4	8"	Oil Bottle
	2-1/4IDx.25 wall	1x2.6"	3"	Socket
Rod	3/4"	2x3-1/4	6-1/2"	Filter Holders
	1/2"	3x11, 12x1	45"	Controller & Standoffs
	2"	2x3-1/4	3-1/4"	Clamps
Angle	3"x1/4"W	1x3"	3"	Clamp Mount
	2"x1/4"W	1x18"	18"	Filter Cartridge
	1-1/4"x1/4"W	8x1-1/2"	12"	Housing Mounts
	3/4"x7/8"W	2x27-3/4"	55-1/2"	Batteries
Bar Stock	3/8"x1-1/2"W	5x2; 1x27-3/4"	37-3/4"	Frame Mounts; Batteries
	1/4"x1"W	2x27-3/4"	55-1/2"	Batteries
	1/4"x3"W	2x19"	19"	Flow Meters
	1"x3"W	3x3"	9"	Clamps
	1-1/4"x3"W	1x3"; 1x2.1"	5.1"	Clamps
Sheet	3/8"	2x6x18	1-1/2′^{2}	Vents; filters
	1/4"	4x6-1/2x6-1/2		Batteries
		3x6x6		Controller
		7075-T6 Aluminum		
	8"OD x .750 Wall	1 @ 32-1/2"; 1 @ 42-1/2"	75"	Housings
	8-1/4"ODx1-1/2" Discs	4 each		End Caps
	1-3/4" Rod	2 x 2"	4"	Blow Off Plug
		Stainless Steel		
	1/4" round rod	2x9"; 4x24"	114"	Batt. safety pins U-Bolts
	3/8" round rod	1x4"		Safety Pins
	1/4" Threaded Rod	6x7-1/2"	45"	Motor housing
	3/8x1" Flat Bar	2x10-1/4"; 2x9-1/2"; 2x4"	50"	Clamps
	3/8" Threaded Rod	2x5"; 4x4.5"; 16x3-1/2"	84"	Clamps, Filters

Stock Item	Stock Size	No. of Pieces and Length	Amount Needed	Description
		Stainless Steel (contd.)		
	1/2" Threaded Rod	4x3.5"		Clamps
	5/8"OD x .065"W	1 @ 2.05; 1 @ 2.8	~5"	Clamps
	1/2" Round Rod	2x3";3x3-3/4"	18"	Clamps
	1-1/8" Round Rod	1 x 2-3/4	2-3/4"	Pump Shaft
		Plastics		
Delrin	1/2"x1-1/2" Flat Bar	6x1-1/2	9"	Batteries
	2-1/4" Rod	16x1-1/8"	18"	Filter Knobs
	3/4" Rod	2x8"	16"	Housing Supports
Acrylic	5-3/4OD x 3/8"W			Cast Acrylic Tube
		1x6"	6"	Pump Motor
	5/8" C.A. Plate	2 @ 6x6	1/2 ft^2	Pump Motor
	3-1/2" Rod Stock	1x1-1/4"	1-1/4"	Pump Motor
	1/4" C.A. Plate	1 @ 5"D		Pump Motor
	1-3/8" C.A. Plate	4 @ 7-1/4"D		Filters
	6" OD x 1/4"W Tube	1 @ 11"	11"	Controller
PVC	1-1/4" sheet	2x7-1/2"D		Filters
	1" sheet	2x6-3/4"D		Pump Motor
	3/4" sheet	6 @ 3x3"		Filter & Meter Mounts
	1-1/4" Solid Rod	8 x 1"		Standoffs
	1/2" SCH 80 Pipe	2x1"; 4x1/2"		Standoffs
	1-1/2" Solid Rod	1/4" thick	1x1-1/2"	0.1 Bottle
Sintered Polypropylene		1/4" thick	4x6"D	Filter Support

O-Rings

147 mm Filter Holders	1 each	2-160/holder
	1 each	2-251/holder
Pressure Housings - End Caps	2 each	2-259/pressure case
		2-261/pressure case
Motor Housing - End Caps	2 each	2-252/assembly
- Shaft Boss → end cap	1 each	2-039/assembly
- Pump Body → Shaft Boss	1 each	2-033/assembly
- Pump Cover	1 each	2-227/assembly
Blow Off Plugs	1 each	2-020/plug
	1 each	2-027/plug
Exhaust Valve Plate	1 each	2-027

APPENDIX B: CRUISE CHECK LIST

In our operation, most of these components are stored in a portable van which goes to sea with us. This simplifies tremendously the process of loading and unloading a ship. The following is a list of items considered essential for pump deployment at sea.

Pumps:

- Frames
- Controllers on end caps
- Batteries
- Intake manifolds
- Battery case end caps
- Filter holders
- V-Band couplings
- Wire clamps - stop pins, upper clamps

Battery Charger(s):

- Cables

Tools:

- Assorted wrenches, sockets, pliers, screwdrivers, etc.
- Drill and drill indexes; cordless drill
- Taps and tap wrench; 1/4-20; 5/16-18; 3/8-16; 1/4" pipe, 1/8" pipe
- Hacksaw
- Pneumatic impact wrench w/socket set, and air hose
- Air lines w/fittings
- Aspirator gun w/adapters for gardena fittings
- Electronics kit
- Multimeter
- Small Oscilloscope
- Tapes, duct & electrical
- Flashlights
- Extension cords
- Rope and tie down line

Accessory Items:

- Bray Oil, 40-50ℓ
- Depth recorders
- Tygon tubing; 1/4"ID x 1/16"W oil resistent tygon formula F4040A; 1/2"ID x 1/8" wall
- Pingers and extra batteries

Spare Parts: Hardware

Nuts, bolts, washers - assorted lengths of 1/4", 5/16", 3/8", and 1/2"
Assorted lengths and head type #4 through #10 machine screws, especially #10-24 and #10-32 used on pumps
Wire clamp sets - 2 or 3 full sets of components
- Hardware for clamps, pin bolts, roll pins
V-band couplings, T-bolts and nuts
Batteries - approximately 50 for 8 pumps
Hose clamps, assorted sizes
Sacrificial anodes - pump frame and battery case
PVC fittings - assorted nipples, couplings, adapters, bushings, etc., primarily 1/4" and 1/2" sizes
Gardena quick couplings and adapter nipples
Polypropylene insert adapters for Tygon water and oil lines
Spacers, gaskets, etc., for oil bottles, filter cartridges, battery cases, etc.
Oil bottle adapters and valves
Garden hose
Rain caps
Flow meter mechanisms, 2 or 3 sets of spares
Tie wraps - assorted sizes
E.O. connector, cables, and bulkhead connectors
MECCA connectors
Flow switches, 4 or 5 assembled units
Amphenol series 44 battery connectors
Diode assemblies with battery stack cables attached
Power relays
Electronics and interface spares: computer ICs, resistors, etc.; stak-on connectors; batteries, computer & I.F.; clip leads; jumpers; test cables
Shrink tubing and heat melt
Scotch kote electrical coating
Dow Corning Silicone grease
Parker O-lube
Anti-corrosion grease
Motor spares - bearings and brushes
Pump components - bodies and end caps; impellers; mechanical seals
Motor housing components - end caps; acrylic tube
O-rings - 10-15 of every size used

APPENDIX C: OPERATION AT SEA

Auxiliary Equipment:

There are numerous items which are essential for dependable pump performance and maintenance at sea. These include battery chargers, compressed air, fresh water, spare batteries and battery stacks, spare pump frame and clamp components, extra oil for the motor housing, test equipment and spare electronics parts.

The battery charger used is made up of 120 VAC 60 Hz variable transformer (Powerstat 1256) with a 30 ampere capacity. The A.C. output is passed through a full-wave bridge rectifier with a 1000 µF filter capacitor to provide a variable D.C. output. A voltage meter and an ammeter are provided to monitor the output of the charger. The associated charging cable is made up from 15m of #16-4 wire with 2 wires tied together for both + and -/voltage. There are 5 pairs of #16 AWG teflon coated wire 3 m long connected to the #16-4 wire with appropriate polarities. The end of each pair is tied to an Amphenol series 44 waterproof connector which mates with the connector on each battery stack. These are three pin connectors so that the same connector on the battery stacks can be used for both charging and discharging of the batteries. This combination is capable of charging 5 pumps or 10 stacks of batteries.

Approximately 40 liters of Bray oil are kept on hand to top off the pumps before each deployment. During normal operating conditions 30-50 ml of oil are lost from each pump. The combinations of pressure and the arcing of brushes on the electric motors causes the oil to gassify. These gases are usually vented off after the pump is returned, and the motor housing is refilled with fresh oil. The oil is kept in four or five 9.5ℓ containers for ease of handling on the deck of a ship and for ease of storage below bench space. When the pump housings are being refilled, these bottles are set on top of the pump frame, and the oil siphons through the oil reservoir at the base of the frame and through to the pump housing from the bottom, thereby easily displacing the air out the top of the pump through the drain cock.

The wire-clamp stops are mounted to the wire with a pneumatic inpact wrench which operates from the compressed air supply on board ship. This usually is relatively convenient to most deck locations and should be supplied at 60-80 psi.

The ship's fresh water supply is used to rinse the pumps down and flush out both the pump and flow meters after retrieval on deck. The compressed air is utilized again in conjunction with a blow-gun aspirator. This is used to suck out any water remaining in the particulate filter holders and then to blow off the excess moisture on the upper end of the frames. This prevents water from dripping onto the batteries when the end cap is removed for charging.

When the particulate filters are removed, they are placed on a 1 x 2-m plywood board with 2.5-cm holes drilled 20 cm between centers. This allows the filters to be changed easily and kept in proper order.

The list of on-board test equipment needed is conveniently short. An analog type multimeter can cover most of the testing which may be necessary, because the slower timing pulses and switch closures, can be easily seen as needle movement. A normally open/normally closed push button switch with three 18" clip leads attached is used to simulate switch closures, which are normally activated via the flow meters. There is also a jumper cable that plugs into the battery stack and is used with the voltmeter and a 10-ohm load resistor to test the condition of the individual batteries. A small portable oscilloscope is very useful for testing the faster electronics on the pump and other accessories, such as telemetering pingers.

A set of battery stacks for 50% replacement is taken along as spares. These are pre-assembled onto spare end caps and prewired for use. Other important spares include the following: electronic components for the printed circuit boards, usually 5 or 6 of each component item, 5 or 6 prewired and assembled flow switches, spare components to repair 3 or 4 flow meters, as well as 2 complete flow meters, spare components to repair 2 or 3 sets of wire clamps, several sets of spare electrical cables and connectors, and a full complement of extra nuts and bolts, plumbing supplies and other hardware items.

Operation:

The preparation procedure for deploying the pumps on the wire requires 2 to 3 hours for one person to perform and includes the following:

A cast sheet is first made out with the desired sample depths recorded for each pump. From this a delay time is calculated by dividing each depth by the wire out speed (we use 40 m/min) to get wire time. Then 5 min is added for each successive pump to be secured onto the wire. The time begins counting down only after the pump is immersed in the water. A reading of actual wire length out (position of the pump on the wire) is also recorded at this time for use by the winch operator during deployment and retrieval. The initial flow meter readings are then recorded to complete the cast sheet preparation.

The Nuclepore filters are loaded into the holders inside the ship's lab. When the holders were first removed from the pumps (previous cast), they were laid out in order on the filter board in numerical sequence. When all the filters are loaded, the holders are remounted on their respective pump frames.

The motor housings are topped up with oil before each deployment. An oil bottle is fitted with approximately 2 m of 0.6-cm I.D. tygon tubing which is attached to the valved fitting on the pump's oil reservoir. With the bottle on the deck of the ship, the valve is opened and oil is allowed to fill the tubing by opening the drain cock at the top of the system. The oil bottle is then raised to the top of the pump frame, and the oil is siphoned into the motor housing from the bottom. Any excess air is vented off through the drain cock on top. When the housing is filled, the drain cock is closed and the oil bottle is lowered. The valve on the oil reservoir is closed, and the tubing is disconnected and drained back into the bottle.

The motors and pumps are tested on deck before deployment by disconnecting the 13-mm tubing from the pump head and hooking the pump up to a bucket of water with two pieces of 13-mm tygon tubing which are about 2 m long. The E.O. 51F2F pigtail connected to the motor is plugged into a pair of 12V batteries wired in series and run for about 30 sec. The current draw of the motor can occasionally be monitored at this time also as a check on the condition of the motor. The normal current draw for the motors with the pump wet and no restrictions in the flow path is between 2.3A and 2.8A. Anything much in excess of this is a good indicator that either the motor is getting worn or that there may be a problem with alignment of the pump head or with the impeller.

After the motors are tested, the plain end caps are usually fastened to the short battery housing. As with all components these are numbered and always used on the same pump. They are carefully inspected for damage or dirt on the o-ring seals. If necessary, these are cleaned or replaced and regreased with Parker O-Lube. The battery stack cable is plugged into the connector on the bottom of the end cap, and the end caps are then gently placed on the housings and pressed down carefully to avoid damaging the o-rings. The V-band clamps are then placed in position and tightened down.

The cartridge filters are now loaded onto the pump frames. There are three cartridges on each pump. The first in the flow path is optional but can be loaded with a blank or clean filter which is used as a backup filter in the event of a breakage in the Nuclepore filters or in the plumbing ahead of the cartridges. The remaining two cartridges are loaded with similar filters which have been impregnated with manganese dioxide (Appendix E). All these filters are handled with plastic gloves to avoid contamination.

The electronic control circuitry should be run through its paces before setting and installing in the pressure cases. Hook up the normally open/normally closed switch to the respective terminals on the printed circuit board and then turn on both interface power and pc 1211 pocket computer power. Check the battery power for both at this time; both should be above 5.2V for deployment. Replace if necessary. Also, hook up 12V power to the relay circuitry. The computer is then programmed with a test program which utilizes a one-minute delay time and a 15-minute pump time. Before the timer starts counting, the sea water switch must be simulated by grounding the appropriate connection to the PCB. When the computer signals the pump turn on, the relay should audibly close and entries should be made by alternately pushing and releasing the N.O.-N.C. push button switch to simulate the action of the magnetic flow switch, which is mounted on the face of the flow meters. During this process, the data should enter into the computer. At the end of the cycle, the computer should signal the pump to turn off. If everything checks out properly, the controllers are now ready to be programmed and installed in the pressure housing.

The initial input data for each controller contains information about the date, the cast number, and the pump number. The delay time relative to the depth of the pump is programmed into the computer as well as the actual time that the pump is to run, i.e., the sampling period. The o-rings are inspected and the controller installed in the pressure housing in the same manner and with the same precautions as with the plain end caps.

All the E.O. cables can be connected to the bulkhead fittings on the end caps at this time. It is recommended that two people double check each other's work for this job since it is essential that all plugs bottom out on the fittings and that the plugs are placed on the correct pins. It is easy to mix things up at this point.

The final plumbing connections can be made to the bottom of the particulate filter holders by use of the Gardena™ quick connect fittings on the intake manifold. Also, reconnect any pumps that were disconnected for previous testing.

After a final, thorough inspection of each pump, a cast sheet is to be distributed to the winch operator and any other interested party on board ship. The pumps are now ready for deployment.

Deployment:

Deployment of the pumps requires a minimum of two people handling the pumps, a winch operator, and a crane or tugger operator.

A 100 kg or greater weight is attached to the end of 13-mm trawl wire and lowered over the side of the ship to the water line. The wire out meter on the trawl winch is zeroed and the weight is lowered about 10 m. The first pump to be mounted is moved in below the A-frame, and the wire stop pin is bolted onto the wire using the pneumatic impact wrench. The pump frame is then hoisted in the air next to the wire using either the air tugger or the ship's crane. The pump is then fed onto the wire through the slot in the frame. Usually, the bottom slot goes in easily and then the pump must be manipulated a bit to line up the upper slot. Once both slots are engaged around the wire, the pump is spun around on the wire so that it falls in tight to the center of the slot. The safety pin is installed at this time. The pump is then lowered along the wire until the pin on the wire stop engages in the socket at the bottom of the pump frame, and the full weight of the pump rests on this pin. The upper wire clamp is then attached and fastened tight. The slings that were used to lift the pump are then removed. A final visual inspection of wiring and plumbing is made and pingers are turned on if attached. The pump is then lowered into the water. The first pump is lowered to the next "wire out" distance on the cast sheet and the above procedure is repeated until all the pumps are mounted and lowered to the appropriate depths.

The retrieval process is essentially the reverse of deployment. As each pump reaches the deck, the slings from the tuggers or crane are attached to the pump. The upper wire clamp is removed after a little bit of tension is placed on the slings. The safety pin is removed and the pump is lifted off of the wire stop pin. As the pump is spun around, it will slide off the wire of its own weight and can then be lowered onto the deck. The pinger, if attached, can now be turned off and the pump can be moved away from the A-frame and secured on deck, while the winch operator is hauling in to the next pump.

The clean-up process and data retrieval can begin after all the pumps have been fastened securely on deck. The flowmeter readings should be recorded first to find any pumps that may not have operated. For these, follow a troubleshooting procedure during breakdown of the pumps. For those that did pump, all the plumbing and electrical connections are removed. The particulate filter holders are sucked dry with the aspirator gun attached to the compressed air supply and they are then removed and placed in order on the filter board in the lab. The pumps can then be thoroughly rinsed off with fresh water. After that, the pump and water meters are flushed out with fresh water for about 30 sec while running the pump from the 24V battery source. This eliminates the possibility of salt crystals forming inside and damaging either the impeller or internal components of the meters. Any excess water is then blown off of the upper section of the pump frames so that the plain end caps and controllers can safely be removed from the battery stacks without water dripping on the electrical connections to the batteries. The end caps are removed, and the batteries are then hooked up to the battery chargers. Plastic caps are then placed over the tops of the pressure cases to prevent water or dirt from entering. The cartridge filters are removed and placed in individual plastic bags, which are labeled with date, cruise number, cast number, and pump number. These are then stored away to be processed ashore. The computers in the controllers are now debriefed and the data are printed out. The data from the computer are a record of switch closures caused by the turning of the flow meters and are an indication of volume of water pumped as well as the time degradation of flow as the filters clogged up and battery power to the pumps decreased. The particulate filters can now be removed from the holders and placed in a properly labeled plastic bag. It is usually most convenient to reload clean filters for the next cast while the holders are open. After 4 or 5 hours of battery charging, the pumps can be prepared for the next cast.

APPENDIX D: TROUBLESHOOTING

Potential problems that may be evident while checking out equipment before deployment:

- Computer does not receive clock updates - Check CD4060 and CD4017 I/O.

- Computer does not receive data entries - Possible bad CD4013, CD40103, or rarely a bad LM339 or CD4023 - check all input/output (I/O) pins to verify operation.

- Relay not working - Does 12V battery direct to relay work? If yes, possible bad CD4013 or CD4098. Check I/O. Rarely possible bad component or circuitry on relay/power board.

- Pump turns on when cables connected - Bad CD4013.

- Short battery life for interface power - Check current of IF Board. Should be ~1.4 MA - if greater, check for hot or warm components. Replace each and recheck current.

- Computer not receiving input from flow switch - Bad wires?

- Pump works well on deck but not at depth - Bad wires or connectors.

Upon retrieval of the pumps on deck, the flow meters should be checked to make sure that the pumps have indeed pumped. This should be done immediately after securing them on deck and before any other post-cast breakdown procedures are performed.

In the event that the pump did not work, the following checks should be performed in order until the problem is located:

- Carefully and thoroughly check all cables; be sure they are in the proper locations and that the connections are fully bottomed out.

- Remove cables and check for shorts or broken wires with an ohmmeter.

- Check for proper plug contact through power cables after the end caps are removed; squeeze, twist, and wiggle all connections and watch for changes in meter readings. Discard and replace any questionable wires and/or plugs.

- Connect motor to external battery to check for proper operation; hook pump up to a water bucket and check for proper pumping.

- Check for bad connections between batteries and end caps.

- Check continuity between sea water switch and contacts on end cap.

- Remove the end caps and prepare to shakedown controller.

- Check computer display - any error messages?

- Check program line in computer for appropriate errors and correct if necessary. Re-enter test run and verify operation. If error occurs, computer may need to be repaired. If no error, check break point of computer program. Mid program - is program waiting for sea water switch (step 40)? Jump LM339 pin 4 to ground. Check operation of SW switch and associated electronics. Check for input to computer. Check battery power for computer. Low power? Replace batteries, re-program and re-test. No power? Check ribbon cable connections to computer for breaks.

- Is program waiting for timing input (step 55), i.e., delay time? Check clock functions, check CD4060 and CD4017 I/O. Check for updates entering computer 1/min.

- Break at 140? End of program. Check relay power function after delay period and turn on. Re-check all connections from relay to pump motor for erratic contacts, broken contacts or shorts.

APPENDIX E: PREPARATION OF ADSORBER CARTRIDGES
by Alan P. Fleer

Filtered seawater is pumped through MnO_2 (manganese dioxide) coated cartridges. The MnO_2 is distributed throughout the cartridge as very small crystals that form from a potassium permanganate ($KMnO_4$) solution. Coating procedure follows.

MnO_2 does not adhere well to polypropylene especially with the added polyvinyl stearate hydrophobic treatment used in manufacture. To overcome this the cartridges are soaked in a series of solutions to saponify the polyvinyl stearate, thus allowing the permanganate solution to wet the polypropylene.

The cartridges are soaked in a strong soap (Liquinox) solution overnight, then dilute NaOH overnight, then dilute HCl for eight hours, then super- and warm-saturate potassium permanganate solution for 24-36 hours. After each soaking the cartridges are rinsed with distilled, deionized water. I have 4 holders in series for the washing. I use 5 gallons to wash 4 cartridges after the soap and hydroxide steps and 10 gallons after the acid and permanganate steps. We have found it is very important that the cartridges remain full of water or soaking solution between steps. Any air that gets into the cartridge tends to increase the hydrophobic effect and leave an area devoid of MnO_2. The concentrations of the soaking solutions are constantly corrected for the dilution by the trapped water in the cartridges (~150 ml/cartridge). The pH of the permanganate solution is constantly monitored and maintained at 9.5-10.0 with occasional additions of ammonia. After the final rinse the cartridges are allowed to drip-dry for an hour or so. Excess permanganate continues to bleed out of the heavier twine around the fiber. They are packed in plastic bags while still damp. There seems to be no oxidation of the polypropylene or any excess permanganate in the damp cartridges.

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16. Abstract (Limit: 200 words)

Eight self-contained, in-situ pumps have been used effectively and routinely by our group for the past six years to collect both particulate and dissolved phases from large volumes of sea water. Multiple pumps are rapidly and easily deployed on the same wire, to any ocean depth, in almost any weather. Each is capable of drawing up to 200 liters per hour through four large Nuclepore™ filters, then through three cartridge filters. Pumping is controlled by a Sharp™ pocket computer suitably interfaced with the pump motor and flow meter. Endurance is about 15 hours. Total flow and flow rate are recorded, respectively, by a mechanical flow meter and the computer.

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